Report No. CG-D-06-93

Innovative Inspection Techniques

Michael J. Goodwin
Edward F. McClave

MAR, Inc.
6110 Executive Boulevard, Suite 410
Rockville, Maryland 20852

FINAL REPORT
JANUARY 1993

Prepared for:

U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, Connecticut 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering, Logistics, and Development
Washington, DC 20593-0001

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report was directed and sponsored by the Coast Guard Research and Development Center. This report does not constitute a standard, specification or regulation.

SAMUEL F. POWEL, III
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-06-93	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle INNOVATIVE INSPECTION TECHNIQUES		5. Report Date January 1993
		6. Performing Organization Code
7. Author(s) Michael J. Goodwin and Edward F. McClave		8. Performing Organization Report No. R&DC 02/93
9. Performing Organization Name and Address MAR, Inc. 6110 Executive Boulevard, Suite 410 Rockville, MD 20852		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTCG39-91-D-E33A21
12. Sponsoring Agency Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, Connecticut 06340-6096	Department of Transportation U.S. Coast Guard Office of Engineering, Logistics, and Development Washington, D.C. 20593-0001	13. Type of Report and Period Covered Final Report June 1992 to January 1993
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A survey of current Coast Guard inspection techniques used to inspect commercial ships is presented. This is followed by a survey of industry and government agencies to identify current inspection techniques used to inspect large structures. Recommendations are included on ways the Coast Guard could improve the current inspection techniques. In general, it was found that visual inspection was the principal technique used for ship inspections. Ultrasonic thickness gaging is also used extensively to verify plating thicknesses.

The current method of inspection appears to be the best judging from what other industries are doing. Improvements in tank lighting for visual inspection or the use of night vision devices show the greatest potential for inspection improvement as reasonable cost. Better access to tank structures is also needed. It is recommended that the Coast Guard consider requiring built-in access provisions for new tankers to reduce the risk of structural problems being missed during inspections.

17. Key Words	18. Distribution Statement
Marine Inspection Nondestructive Testing	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

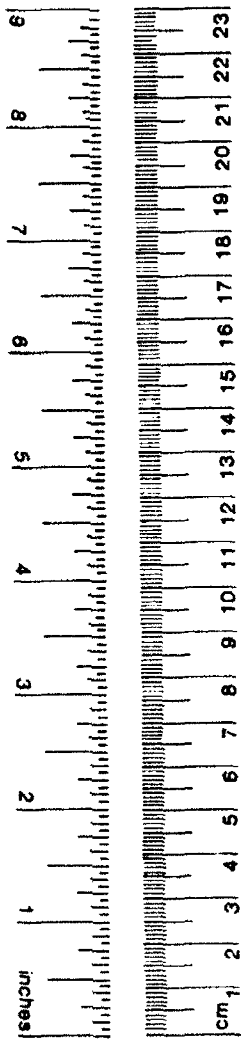
Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

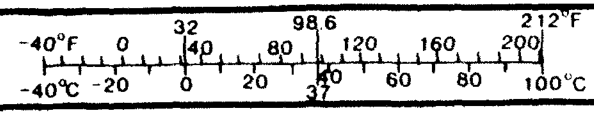


TABLE OF CONTENTS

Acknowledgements ix

Executive Summary x

1.0 INTRODUCTION 1

2.0 REVIEW OF INSPECTION PROCEDURES 3

3.0 INSPECTION EQUIPMENT USED BY COAST GUARD MARINE INSPECTORS 5

4.0 SUMMARY OF SURVEY OF U.S.C.G. MARINE INSPECTORS 6
- 4.1 General Findings 6
- 4.2 Visual Inspection 7
  - 4.2.1 Lighting 7
  - 4.2.2 Magnification 7
  - 4.2.3 Video techniques 7
  - 4.2.4 Summary 8
- 4.3 Physical Access 8
  - 4.3.1 Built-in Access Provisions 8
  - 4.3.2 Rafting 8
  - 4.3.3 Staging 8
  - 4.3.4 Summary 9
- 4.4 Close-up Testing 9
- 4.5 Non-Equipment-Based Techniques 9
- 4.6 Coordination with other Inspection Agencies 10

5.0 INDUSTRY SURVEY OF NONDESTRUCTIVE TESTING TECHNIQUES . . . 11
- 5.1 General 11
  - 5.1.1 Current Commericial Testing in the Shipping Industry 11
  - 5.1.2 General NDT Considerations 11
- 5.2 Visual Inspection 12
  - 5.2.1 Illumination 13
  - 5.2.2 Telescopic Aids 24
  - 5.2.3 Borescopes and Endoscopes 25
  - 5.2.4 Remote Video 26
  - 5.2.5 Night Vision Devices 28
  - 5.2.6 Diffracto Sight (D-Sight) 31
- 5.3 Dye Penetrant 33
- 5.4 Ultrasonics 35
- 5.5 Multiple Probe Ultrasonic devices 37

TABLE OF CONTENTS (Continued)

5.6 Magnetic Particle Inspection 38
5.7 Eddy Current Testing 39
5.8 Alternating Current Potential Drop (ACPD) and Alternating Current Field Measurement (ACFM) 40
5.9 Acoustic Emissions 41
5.10 Radiography 43
5.11 Weld Surface Microstructure 44
5.12 Thermography 45
5.13 Shearography 45
5.14 Vibration Monitoring 46
5.15 NDT Summary 47

6.0 INDUSTRY SURVEY OF ACCESS ENHANCEMENTS 50
6.1 Access Provisions on Ships in Service 50
6.1.1 Installed Ladders and Walkways 50
6.1.2 Inspection from the Tank Bottom 52
6.1.3 Climbing 52
6.2 Portable Ladders 54
6.3 Fixed Staging 54
6.4 Rafting 55
6.5 Work Platforms Suspended from Overhead 56
6.6 Articulated Work Buckets 58
6.7 Magnetic Crawlers 59
6.8 Remotely Operated Vehicles (ROVs) 60
6.9 Divers 62
6.10 Robotics 63
6.11 Access Summary 64

References 66

Sources Contacted for this Report 68

APPENDIX A Interview with MIO New York Marine Inspectors 73

APPENDIX B Interview with MSO New Orleans Marine Inspectors 75

APPENDIX C Interview with MSO Portland Marine Inspectors 77

APPENDIX D Interview with MSO Honolulu Marine Inspectors 81

APPENDIX E Product Brochures . . . . Volume II

List of Figures

Figure ES-1 Summary of NDT Techniques xi
Figure ES-2 Summary of Access Enhancement Techniques xii

Figure 1 General Inspection Phases 3
Figure 2 Proportion of Access Methods Used by Coast Guard Inspectors 9
Figure 3 Typical Borescope Design 25
Figure 4 Typical Mini Camera Size 26
Figure 5 Helmet Mounted Night Vision Device 29
Figure 6 Night Vision Pocketscope 29
Figure 7 D-Sight Setup 31
Figure 8 Center Fuselage Section of a Commuter Aircraft 33
Figure 9 3mm Thick Aluminum with Fatigue Cracks 33
Figure 10 Hand-held Ultrasonic Thickness Gauge 35
Figure 11 Oscilloscope Based Ultrasonic Thickness Gauge 36
Figure 12 MAUS II 37
Figure 13 Magnetic Yoke 39
Figure 14 ACFM Equipment 41
Figure 15 Acoustic Emissions System for Experiments 42
Figure 16 X-Ray Test Equipment 43
Figure 17 Climbing Safety Devices 53
Figure 18 Fixed Staging 55
Figure 19 Rafting 56
Figure 20 Suspended Staging in Tank 56
Figure 21 ST-26 Mini-Spider 57
Figure 22 SC-30 Spider Climber 57
Figure 23 Portable Work Platform 59
Figure 24 Magnetic Crawler 60
Figure 25 Typical ROV 61
Figure 26 Possible Robotic Arm Configuration 64

List of Tables

Table 1 Comparison of Standard Flashlight Bulbs 15
Table 2 Xenon Bulbs 15
Table 3 Typical Flashlights 17
Table 3 Typical Flashlights (Continued) 18
Table 3 Typical Flashlights (Continued) 19
Table 3 Typical Flashlights (Continued) 20
Table 3 Typical Flashlights (Continued) 21
Table 3 Typical Flashlights (Continued) 22
Table 4 Typical Headlamps 23
Table 5 Typical Personal Flashlights 24
Table 6 Characteristics of Typical Night Vision Goggles 30
Table 7 Hand Held Night Vision Devices 31
Table 8 Vision Enhancement Methods 47
Table 9 Nondestructive Testing Methods 48
Table 9 (Continued) Nondestructive Testing Methods 49
Table 10 Access Enhancement Methods 65

Acknowledgements

The authors wish to thank Cramer & Lindell Engineers, Inc. of Niantic, CT who provided us some very good insight into the costs involved with nondestructive testing. Mr. Dave Orloski of Cramer & Lindell Engineers was particularly helpful.

Connecticut Analytical Corporation assisted by providing a list of equipment needed for a remote video system that could be used in marine inspection.

Executive Summary

This report provides the results of a three phase project. In the first phase, U.S. Coast Guard marine inspectors were surveyed to gather information regarding current Coast Guard hull and structural inspection techniques and equipment. This formed the baseline for comparison to new inspection technology. In the second phase, Government agencies and industry were surveyed to identify potential techniques that could be applied for structural inspections on ships. In the third phase, the feasibility of incorporating the inspection technology, identified in phase 2, into the Coast Guard marine inspection program was evaluated.

The current method used by Coast Guard inspectors is a visual walk through. When an inspection problem is found during the walk through, the inspector can require the owner to perform other nondestructive tests (NDT) to determine the extent and severity of the problem. The inspector can also require additional staging to allow close-up inspection of suspected problem areas. Coast Guard inspectors do not order routine NDT to help locate potential problems. Coast Guard inspectors have limited training in NDT other than in visual inspection and rely on qualified technicians to perform most NDT tests.

The Government agencies and industry survey covered two broad areas, NDT techniques and access enhancement techniques. Most of the techniques used by Government and industry inspectors are familiar to Coast Guard inspectors. Many are used to some extent now during NDT inspections by owners. Ultrasonic testing is widely used to determine plate thickness but most other methods are used infrequently. The survey attempted to identify all the potential techniques that could be used for shipboard structural inspection.

Figures ES-1 and ES-2 summarize NDT and access enhancement techniques, respectively, that have potential and are worth further developmental effort by the Coast Guard. Many of the methods listed as needing no additional study are useful for shipboard inspection but are already well developed or are continually being improved by industry so that additional Coast Guard development is unnecessary.

The techniques that offer the biggest return on investment are improved lighting for inspectors and improved requirements for permanent ladders and walkways within tanks on new construction. Better lighting was cited by inspectors as their number one need. This could take the form of better flashlights or other portable in-tank lighting. The shipping industry is moving slowly towards providing better access built in to the structure of new ships but the Coast Guard could speed up the process through regulatory action. With the advent of double side wall and double bottom tankers, the time is right to make improved access a part of the design.

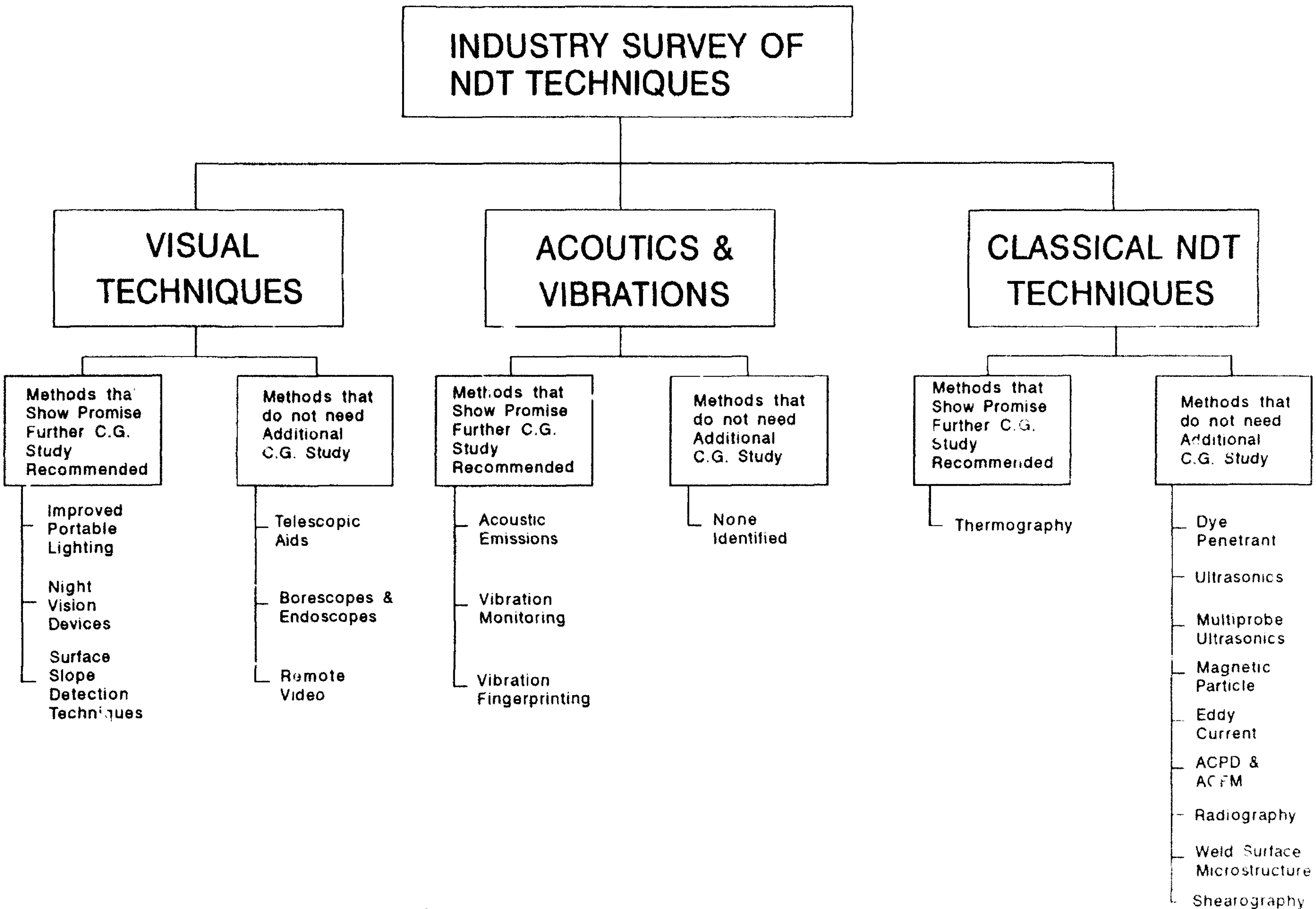


Figure ES-1 Summary of NDT Techniques

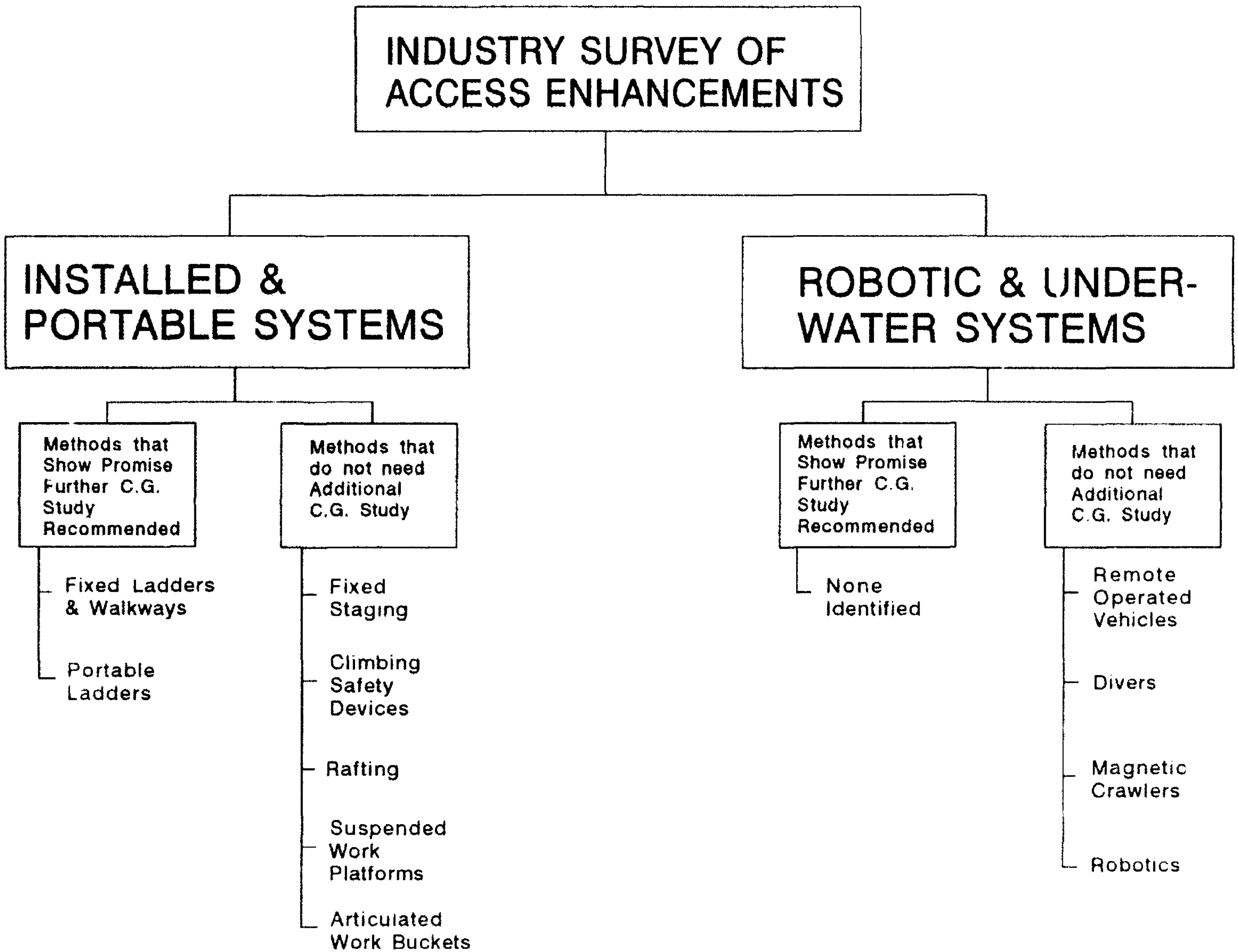


Figure ES-2 Summary of Access Enhancement Techniques

1.0 INTRODUCTION

The intent of a U.S. Coast Guard structural inspection of a merchant vessel is to obtain an overall impression of the structural integrity and corrosive condition in a relatively short period of time. Ideally 100% of the spaces in the vessel should be inspected. However, this is not always possible so the vessel's condition is often determined from an inspection of a sample of the spaces on board.

The current method used by Coast Guard inspectors is a visual walk through. The purpose of a visual inspection is to confirm the as-built condition of the structure, detect damaged structural elements, and detect corrosion damage. Within each space, inspection is generally restricted to areas readily accessible from ladders and walkways, such as decks, stringer platforms and bottom structures. Special staging is not used unless it is already in place for other purposes or a problem requiring close up inspection is noted by the inspector. Because staging is installed at the owner's expense, Coast Guard inspectors minimize the amount of staging requested.

When a suspected problem area is found during the inspection, the inspector can require that the owner perform other nondestructive tests (NDT) and nondestructive evaluations (NDE) to determine the extent and severity of the problem. Since this work is at the owner's expense, Coast Guard inspectors do not order routine NDT examinations to help them locate potential problems. However, classification societies such as the American Bureau of Shipping (ABS) do require periodic ultrasonic surveys to determine structural thickness as a requirement for classification. The Coast Guard inspectors can obtain access to this data if needed.

All forms of nondestructive testing require trained operators to properly perform the tests and correctly interpret the results. Visual inspection, the oldest form of NDT, is no different. The Coast Guard inspector is the operator performing the visual inspection. The inspector requires training in two respects. First, the inspector must know how to visually locate potential structural problems. Second, the inspector must be able to evaluate the potential impact on the safe operation of the vessel of any cracks, corrosion, etc., that are found. Regardless of the type of NDT used, the Coast Guard inspector must employ this second type of knowledge. At present, the Coast Guard relies to a large extent on the inspector's prior education or experience to provide the needed training for visual inspection and for determining the effect of defects on continued safe operations.

Training for Coast Guard inspectors in forms of NDT other than visual is generally not provided except for introductory courses on the subject. The inspectors rely on qualified technicians hired by the owner to perform NDT tests and report the results. The level of training required makes it infeasible to train and certify Coast Guard inspectors in other forms of NDT. Nevertheless, the Coast Guard inspectors should have a basic understanding of the capabilities of each type of NDT so that proper tests can be required and their results accurately interpreted. The Officer in Charge of Marine Inspection, OCMI, and Chief of the Inspection

Department, CID, are often involved in evaluation of NDT results and require training, as well. The courses currently provided to inspectors provide the basic understanding needed.

The project discussed in this report consisted of (1) a survey of Coast Guard marine inspectors to determine inspections techniques used by the Coast Guard, (2) a survey of industry and government agencies to determine NDT techniques that might be used for marine inspection, and (3) an evaluation of which of the techniques used by others might benefit Coast Guard marine inspection. Sections 2.0 through 4.0 discuss the results of the survey of Coast Guard inspectors. Section 5.0 of the report covers NDT techniques in use by industry and Government agencies for inspection of large, complex structures. Section 6.0 covers different means of gaining access to the structure located high in a tank for purposes of inspection. The usefulness of each NDT technique or means of gaining access to the Coast Guard marine inspection program is discussed in sections 5.0 and 6.0, as well. Recommendations are also made in these sections concerning the need for additional research and development in certain of the areas which are most promising.

2.0 REVIEW OF INSPECTION PROCEDURES

Coast Guard (CG) inspectors are required by law to perform a "close-up visual inspection" of all certificated U.S. flag vessels during each inspection for recertification. This inspection must cover the outside of the hull, deck, and superstructure, and all internal spaces. Because of the size and structural complexity of many of the vessels inspected, the limited inspector manpower, and physical barriers which prevent an inspector from actually coming within reach of every structural component of a vessel, inspection protocol has evolved into four distinct phases, as summarized in Figure 1.

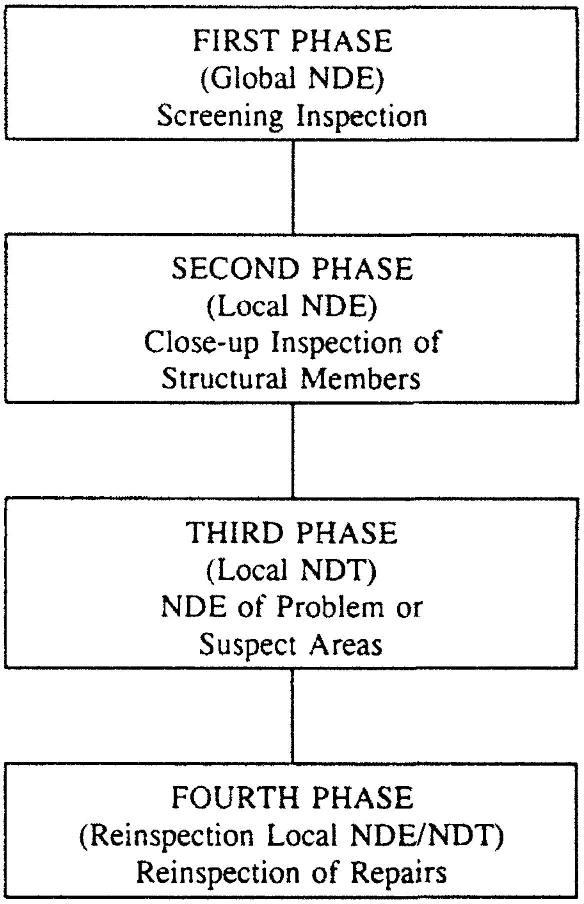


Figure 1 General Inspection Phases

The first phase of the structural inspection of a particular space is a scanning or screening inspection, which may involve observation of the outside of the hull and bottom adjacent to that space and always includes entry into the space and at least a cursory visual inspection from accessible locations within that space. This phase is always conducted by a CG inspector, who may be accompanied by shipowner's representatives, ship's officers, shipyard personnel, or by independent marine surveyors or classification society surveyors (generally ABS).

The second phase is an actual close-up inspection, preferably involving close physical proximity, of areas or structural members which were identified during the screening phase as warranting closer attention, or which are known to be susceptible to failure by virtue of the vessel's repair history or for other reasons. This phase of the inspection is also always conducted by the CG inspector, who may be accompanied by others.

The third phase of an inspection is nondestructive testing of areas identified as having problems. This phase is conducted by shipyard personnel or independent NDT contractors, at the expense of the vessel's owners, and is done at the request of the Coast Guard. A CG inspector may or may not observe the actual inspection; but, the results are reported to the CG inspector.

The final phase is the reinspection of repairs required or suggested by the CG. This is also always done by a CG inspector, although not necessarily the same inspector who conducted

the initial inspection. The Coast Guard inspector may have outside consultants or NDT contractors verify the repairs as well.

In the case of vessels or classes of vessels having a history of significant structural failures, or for those travelling routes over which vessels are known to encounter severe conditions leading to structural failures, the CG has instituted the Critical Areas Inspection Plan, CAIP. Vessels subject to CAIP have accelerated inspection schedules and owners of such vessels are required to provide enhanced access to CG inspectors for screening purposes. Vessels of the Trans-Alaska Pipeline Service (TAPS) are all subject to CAIP, as are a number of others.

Nondestructive testing such as ultrasonic thickness gaging is done by shipyards or by outside contractors at the expense of a vessel owner. The Coast Guard's use of such tests is somewhat different from that of the classification society surveyor. Coast Guard inspectors generally require thickness gaging to be performed only in the case of evident deterioration, and only in the specific area which is suspect. Classification societies require overall thickness gaging for screening purposes at specific intervals.

CG inspectors often have access to classification society survey results and reports, and use these as background information. In certain cases, surveys, or portions of surveys, by independent surveyors or by classification society surveyors have been accepted by OCMI's as partially fulfilling CG inspection requirements.

In summary, most of what the Coast Guard inspector does is visual inspection. This may be followed by a review of more detailed NDT conducted at the owner's expense.

3.0 INSPECTION EQUIPMENT USED BY COAST GUARD MARINE INSPECTORS

U.S. Coast Guard marine inspectors were interviewed in New York, New Orleans, Portland OR, and Honolulu. The purpose of the interviews was to determine the needs of inspectors for improved inspection equipment and technology, and to determine the inspectors' impressions or opinions of unusual or innovative inspection technologies which they had used or seen in operation. More detailed comments from the visits to each location are contained in Appendices A through D.

Coast Guard marine inspectors generally travel to an inspection site carrying nothing more than a small utility bag containing small tools (such as a scrapper and chipping hammer), flashlight, oxygen sensor, and sometimes an emergency breathing apparatus, along with a few reference books and note-taking equipment. In almost all cases, the inspectors' equipment is limited to what they can carry.

Any equipment which is necessary to provide enhanced physical or visual access, such as staging, high-powered lighting, optical or video equipment is provided by the shipowner or by the shipyard, at the expense of the shipowner.

Present Commandant (G-MVI) and local inspection department policies do not allow inspectors to require shipowners to provide access enhancement or testing equipment unless the inspector has evidence of a specific problem which needs closer inspection.

In most cases, deep-draft tank and cargo vessels are inspected while the vessel is in a shipyard, and staging or enhanced lighting is often available to the inspector incidental to normal shipyard work. In many cases, inspection offices have a very good relationship with shipowners and the owners often voluntarily provide extra staging in the spaces the inspector is going to inspect.

4.0 SUMMARY OF SURVEY OF U.S.C.G. MARINE INSPECTORS

4.1 General Findings

Discussions were held with experienced inspectors to find out what inspection techniques they now use or had used in the past for ship inspections. A survey of the different means of access used was included. The results of the survey were relatively unproductive because few inspectors had any useful first-hand information about novel or unusual inspection techniques. The primary reason for this is, as mentioned above, CG inspectors are generally limited both by logistics and by inspection policy to a few simple tools which they can carry with them, and thus they do not generally have any hands-on experience with technologically advanced inspection equipment.

A number of inspectors felt that trying to improve inspection effectiveness by evaluating heavy, expensive, complicated equipment did not address what they considered the "real problem". The "real problem" which they cited was that inspectors have increasing administrative workloads which impinge on the time they have available to conduct inspections. The difficulties and delays in dealing with the Marine Safety Information System, MSIS, and the burden of keeping current with an increasingly large volume of constantly changing regulatory and reference materials are among the examples of administrative workload which inspectors referred to.

In many cases, the interviews for this task were conducted consecutively with interviews for another task involving a portable computer system to be used for entering inspection data on site. Many inspectors felt that the potential benefits of such a system in streamlining the inspection book format, eliminating unnecessary copying and transcription of information, improving communication with MSIS, and providing better access to regulatory and reference materials would provide more benefits than the use of advanced NDT technology in inspections.

As a general rule, inspectors felt that more time, rather than better equipment, would result in the greatest improvement in inspection effectiveness, and that a decrease in their administrative burden would free up the necessary time.

In cases where inspectors had suggestions about inspection equipment, their focus was primarily on improving physical and visual access during the screening stages of an inspection, since the use of high-technology close-up inspection equipment is generally the responsibility of contractors brought in only after the CG inspectors uncover a problem during their screening inspection.

4.2 Visual Inspection

4.2.1 Lighting

The most common complaint among inspectors was a lack of suitable lighting to conduct the screening phase of an inspection. Many times, screening of a large cargo tank must be done by an inspector operating primarily on the tank bottom. Because of the size of the tank, the rough, dark, nonreflective surface, and the types of lights available, it is often difficult for an inspector to see far up on the bulkhead of a tank or to evaluate the underdeck structure from the bottom. A large tank on a 70,000 dwt tanker could be 105' x 45' x 55' high. On a VLCC the same tank might be 200' x 170' x 110' high. Even without structure present, it is difficult to inspect tanks on either of these ships from the tank bottom using a hand-held light.

Inspectors have tried virtually every available portable lighting device, and found that each one has drawbacks, as they are all designed primarily for some other application. The inspectors' flashlights are without a doubt their most used and most valuable piece of equipment. A light designed specifically for the inspection task would be well-received by the inspectors. Such a light would be optimized for the task in terms of size, weight, durability, light output, battery life, beam pattern, and the color of the light projected.

Inspectors have seen several types of non-portable high-intensity lighting in use. High pressure sodium floodlights, of the type often used in large sports arenas, hung from openings in the deck, are one of the few lighting systems with sufficient output to really light up a tanker's cargo tanks. However, inspectors are blinded if they look directly at the light, and this is almost unavoidable. A light of this type with a shield to prevent persons below it from viewing the bulb directly might be of value. The required warm-up time of these lights before they achieve maximum power output also presents a problem.

Theater-type spotlights have also been used. These require a fixed mounting and a separate operator in addition to the inspector. Coordination of the beam direction with the inspector's desires is sometimes difficult.

4.2.2 Magnification

Inspectors have used binoculars with some success. The primary difficulty is aiming a flashlight beam and holding the binoculars at the same time. Night-vision glasses with magnification were mentioned but no inspectors we met had direct experience with them in an actual inspection environment.

4.2.3 Video techniques

Some inspectors have seen demonstrations by private contractors of remote video cameras, with zoom magnification and directed lighting, connected to an above-deck display

monitor. This system could potentially allow a screening inspection to be conducted without the entry of personnel into a space. In practice, capabilities are limited by vibration response, disorientation of the viewer, and the difficulty in concentrating on the screen image for extended time periods. Vibrations and associated image blurring are particularly troublesome when higher magnifications are used.

4.2.4 Summary

In summary, inspectors would prefer improved portable lighting over any other advanced visual inspection improvement.

4.3 Physical Access

4.3.1 Built-in Access Provisions

The design of cargo tank internal structure makes access to bulkheads, stringer platforms, and the underdeck structure difficult.

Many inspectors would like to see vessels designed to be more "inspector-friendly". While this would obviously be expensive to vessel owners, there is a clear precedent for such a requirement in the CAIP program as implemented on TAPS tank vessels. Owners of such vessels are required to stage the tanks at regular intervals to allow CG inspectors enhanced access during screening inspections. Such staging is very expensive, and, over the life of a vessel, undoubtedly costs more than structural modifications during construction to allow enhanced inspector access.

Rather than ladders, walkways, and catwalks, which are generally of light gauge material and subject to more rapid deterioration than the vessel's structure itself, inspectors would prefer to see access enhancements built into the structure in the form of wider longitudinals, handholds cut into structural members rather than welded on, etc. Non-metallic ladders and catwalks were mentioned as another possibility; fiberglass is the most mentioned material for these, however, its long-term stability in crude oil should be studied.

4.3.2 Rafting

Inspectors have had some experience with rafting and consider it an effective technique for inspecting upper areas in tanks, but too expensive, fatiguing, time-consuming and dangerous for general use in the screening stages of inspections.

4.3.3 Staging

Some inspectors felt that at least some of the aspects of the CAIP program, in particular those under which vessel owners are required to routinely provide staging in tanks to facilitate the screening phase of structural inspections, should be extended to more vessels.

4.3.4 Summary

Physical access is critical to performing a complete screening inspection. Improvements in this area would greatly improve the quality of inspections overall. Though few inspectors had hands-on experience with NDT equipment, several different means for gaining physical access were within the inspector's experience. The approximate percentage of access techniques used is displayed in Figure 2.

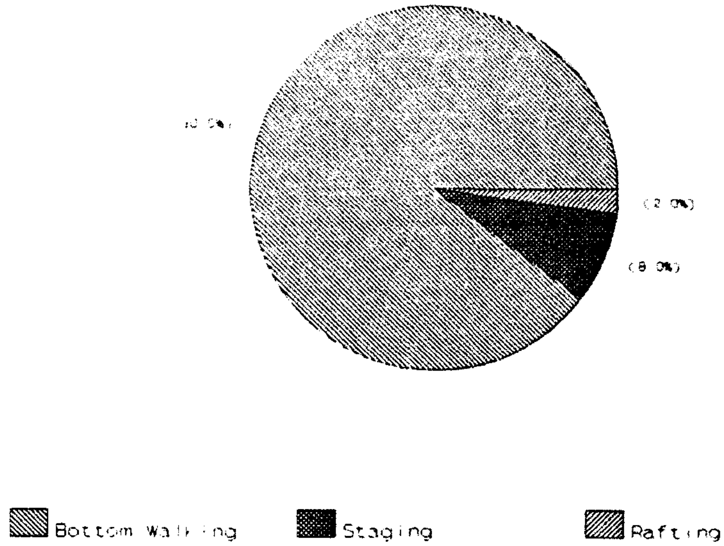


Figure 2 Proportion of Access Methods Used by Coast Guard Inspectors

4.4 Close-up Testing

Inspectors have little direct experience with nondestructive testing techniques, although they do often rely upon NDT reports from outside experts. In general, inspectors seem satisfied with the present technology for thickness gaging and weld inspection in small areas.

Detection of small cracks in the outer shell plating of vessels is difficult and these are often found more or less by accident by trained and attentive observers. A scanning technique which could pinpoint the location of cracks or which could at least indicate the existence of cracks in a general area would be helpful.

4.5 Non-Equipment-Based Techniques

Experienced inspectors stressed that the overall level of technical education and hands-on inspection experience among inspectors has been decreasing for some time and that this trend continues. A large factor in inspector efficiency has always been the value of experience in helping inspectors to decide where to focus their efforts. As this level of experience declines, inspectors can be expected to use their time somewhat less efficiently, expending less inspection effort in those areas of a particular vessel where past experience or observations of present conditions indicate that problems are most likely to occur.

A suggestion advanced by several inspectors, but by no means universally supported, is to expand the use of inspection assistance, possibly with the help of a computer system, to help focus the efforts of the less experienced inspectors. Among the specific proposals are an increased use of statistical techniques based on details of vessel and class repair histories, and

training and inspection aids which incorporate specific details of a number of senior inspectors' experience, beyond that already available in the Navigation and Vessel Inspection Circulars, NVICs, the Marine Safety Manual, MSM, and other guidance documents, and in training courses.

4.6 Coordination with other Inspection Agencies

In many cases, the same uniformed senior inspectors who pointed out that the preparation and experience levels of uniformed Coast Guard Inspectors are decreasing felt that either an expanded dependence upon civilian Coast Guard inspectors or an increasing acceptance of classification society and/or independent surveyor's reports in lieu of detailed structural inspections by Coast Guard inspectors would improve the effectiveness of inspections.

There are precedents for acceptance of third-party surveys as part of the CG inspection, under the broad supervision of Coast Guard inspectors. For example, in Portland, Oregon, Coast Guard inspectors have a close relationship with local independent marine surveying firms and classification society surveyors. In Portland, most inspections are conducted on vessels in local shipyards, and are often concurrent with classification society surveys and surveys conducted for owners by independent surveyors. Cdr. Tom Curelli, CID in Portland Oregon, has accepted surveys by independent marine surveyors, conducted under oversight of Coast Guard inspectors, as partial fulfillment of Coast Guard hull inspection requirements. He showed the contractor a survey of a tankship by a local firm, Ronald Nisbet and Associates, which he felt was of high quality and which had been accepted as part of a Coast Guard marine inspection.

5.0 INDUSTRY SURVEY OF NONDESTRUCTIVE TESTING TECHNIQUES

5.1 General

5.1.1 Current Commericial Testing in the Shipping Industry

A visit was made to the American Bureau of Shipping (ABS) and discussions were held with a few tanker operators to determine the extent of current NDT used in the shipping industry beyond that that occurs during Coast Guard inspections. By far the most widely used NDT technique is ultrasonic plate thickness measurements which are required by ABS for a vessel to maintain ABS class. Visual inspections are performed routinely to determine necessary repairs before a ship enters a shipyard. These inspections are often performed by private inspectors hired by the owners. The private inspector arranges for the necessary staging as part of the contract with the owner. These inspections are usually much more detailed than Coast Guard inspections. Detailed drawings are often provided to the owners showing the location and extent of all problem areas. Shipping companys' have developed quite extensive databases, particularly for ships in the Alaskan trade, showing where damage has occurred over time on the ships structure. The need for more thorough inspections on ships in the Alaskan trade has led some companies, such as ARCO, to consider providing more built in access on new ships so that portable staging does not have to be used as much as on older ships.

ABS inspectors also rely on visual inspection when they survey a ship. This is supplemented by a detailed ultrasonic inspection contracted for by the owner. Other NDT techniques are used on occasion to check the quality of repairs such as magnetic particle or radiographic weld inspections. These are not routinely used to locate damage, however.

5.1.2 General NDT Considerations

Regardless of the NDT technique used, metal surfaces must be cleaned to remove wax, loose paint and sludge. Even a thin layer of wax makes it nearly impossible to detect cracks or corrosion. Wax is not removed by crude oil washing of cargo tanks. Only a hot water wash will clean the tanks adequately. This contaminated wash water must be retained for discharge to shore under current regulations. Though not covered in this report, methods which improve tank cleaning at lower cost or with reduced risk of contaminating the environment would enhance inspections, as well.

Each NDT technique requires a separate certification/qualification process for a person to become a qualified inspector. The standards for the certification of inspectors are set by the American Society for Nondestructive Testing (ASNT). For each technique there are several levels of expertise which can be achieved only through many hours of classroom time and years of experience in the field. Level II training is required to qualify an inspector to interpret test results. Actual certification requirements for each technique and level are beyond the scope of this report. However, it is important to note that it takes many years for inspectors to become qualified.

Some factors that are often overlooked when requesting NDT services are definition of the scope of the job, the difficulties involved with gaining access to a shipyard, the type of report desired, and the required operating procedures and guidelines to be followed. An understanding of the physical principles governing NDT and the equipment used is necessary for defining the NDT tasks to be performed. Procedures and guidelines should follow ASNT recommended practice SNT-TC-1A. A complete job specification must be clearly defined in order for the costs to be estimated and adhered to. Also, an actual inspection may take only 3 or 4 hours to perform, but the contractors may spend an entire day just gaining access to the shipyard if security checks are involved. The owners prepare the necessary job specifications. However, the inspector should be aware that more is involved than just a few hours of the NDT technicians time.

Because of the amount of training required for most of the NDT techniques described below, it is assumed that the Coast Guard will continue to require the use of outside, trained technicians to perform the NDT. Training requirements have not been included in the discussion of NDT techniques except where it is practical for the Coast Guard inspector to master the necessary skills in a reasonably short time. If interested, specific training requirements for eacn technique are given in "Recommended Practice SNT-TC-1A" and "A Guide to Personnel Qualification and Certification" both available from ASNT.

Examples of some NDT equipment are shown in the sections where they are discussed. Other examples are shown in Appendix E. These are shown as examples of products on the market and do not indicate an endorsement of a particular product as being better or worse than any others on the market. Prices for equipment quoted were provided by specific manufacturers. These prices represent typical costs for equipment if ordered today and are subject to change with time. The costs of competing equipment may be higher or lower than the prices quoted but should near the prices cited.

5.2 Visual Inspection

Visual inspection is the primary nondestructive testing method in use today. It is required by law and used by Coast Guard inspectors, classification society surveyors and owner's surveyors. In addition to being fast and inexpensive, it is the simplest and easiest method. The eyes have no match when it comes to scanning and evaluating small objects or large structures. There is no substitute for a direct view of the object being inspected. This is the reason for the continued value of visual inspection, the oldest of all the NDT methods. The basic requirements for a successful visual inspection are adequate illumination, a physically fit inspector, and an inspector trained to know what to look for. Of course, for the visual examination to be successful, the inspector must have good eyesight. Inspectors should be tested for near and farsightedness and for color vision.

As with any other form of NDT, visual inspectors require training to do their jobs properly. This is especially important when the structure is as complex as a ship's hull. The

inspector should know where defects are likely to occur to efficiently conduct a survey. The obvious limitation of unaided visual inspection methods is that they only detect large and clearly visible defects.

5.2.1 Illumination

Good illumination is essential to performing an adequate visual inspection. Often, illumination in a vessel's compartments is very poor. This is particularly true in large cargo or ballast tanks which have no installed lighting.

Temporary lighting can be installed for purposes of the inspection but it is often impractical to do so because of the expense involved or the need to certify the space safe for hot work. In large tanks, considerable lighting would need to be installed to adequately light the space. There are large flood and spot lights commercially available which could do the job. Several portable floodlight manufacturers were contacted and the consensus was that the high pressure sodium lamps were best suited for the job because of thier softer color which is easier on the eyes if accidently stared into. The companies suggest one or two 500 Watt of 1000 Watt lamps would be sufficient to light up a typical tank. The lamps are mounted on a tripod or wheel base and can adjust up or down 90 degrees and rotate 360 degrees. Another possibility is to lower a lamp through an access hatch of the tank so that it hangs 5 feet to 20 feet below the top of the tank. This would light up the lower areas as well as the underside of the tank top. The lights require standard 120 VAC, 60 Hz power.

There are some disadvantages with using flood lighting. First is the possibility of blinding the inspectors if they look into these very bright lights. This could be corrected by using some sort of diffuser or filter, at the expense of light output. The second is the excessive heat generated by the lamps. The space must be either certified safe for hot work or an explosion proof light used. It may be possible to design an explosion proof high intensity light if cooling can be provided. This could be achieved by pumping low pressure air or inert gas to cool the lamps. One other disadvantage is that the lights must be moved from tank to tank and may require significant set up time.

Because of the expense and time involved to setup temporary lighting, the inspectors rely primarily on lights they can carry with them. A standard flashlight has limited usefulness during an inspection because it does not provide adequate light and must be held. Hard hat mounted lights are somewhat better since they free the inspector's hands. Standard incandescent headlamps still do not provide adequate light and are difficult to direct to the spot being inspected. The lack of a good source of illumination was cited by the majority of the marine inspectors interviewed as one of the major deficiencies in the way inspections are conducted today.

Flashlights can be purchased with a wide variety of features, such as: an adjustable beam, waterproof, floatable, rechargeable batteries, circuit breaker protection, different types of reflectors and high output bulbs using Xenon, Krypton or Halogen. Dorcy International is the

only one who manufactures a Xenon bulb for their flashlights. The Xenon bulb is claimed to be brighter than Krypton or Halogen bulbs. An adjustable beam feature allows focusing of the light by twisting the head of the flashlight, thereby moving the lens in relaticn to the bulb. Current rechargeable batteries generally offer limited life, approximately 1.5 hours. Circuit breaker protection instantly disconnects the bulb from the battery in the event of a broken bulb.

Many manufacturers produce flashlights that are approved for use in hazardous locations. Associations that offer approval for these are Factory Mutual, Mine Safety and Health Administration (MSHA), Underwriters Laboratories (UL), Canadian Standard Association (CSA) and the American Society for Testing and Materials (ASTM).

The brightest bulb types available for flashlights are Xenon, Halogen and Krypton, these gas filled bulbs run very hot. Standard incandescent flashlight bulbs are available in different sizes and voltages and have lamp designations PR-2, PR-3, PR-6, PR-7 and PR-12. PR-6 and PR-3 bulbs are used in 2-cell and 3-cell standard military flashlights, respectively. These flashlights meet MIL-F-3747E.

The brightness of bulbs, tested at a constant design voltage, is measured as the Mean Spherical Candlepower (MSCP). Luminous flux is a measure of the light energy in the visible spectrum. The unit of measure of luminous flux is the lumen. If a light source produces 1 lumen per steradian, the source in a 1 candela source. All of the light coming from a one candela source measured over the 4π steradians of the surrounding sphere is equal to one spherical candlepower. Since the light is not uniform at all angles for an actual lightbulb, the mean spherical candlepower is used as a measure of light output. The MSCP is measured using an integrating spherical chamber. The bulb is placed in the center of a clam shell sphere which is painted white on the inside. The bulb operates at a constant design voltage and a photocell measures the brightness intensity reading on the inside of the sphere. Table 1 shows the design voltage and MSCP for common bulbs and for some Krypton and Halogen bulbs. Table 2 gives the MSCP and lumens for Xenon bulbs used in Dorcy International flashlights.

Table 1 Comparison of Standard Flashlight Bulbs

Lamp Designation	Design Volts	Lamp MSCP
PR-2	2.38	0.8
PR-3	3.57	1.5
PR-6	2.47	.45
PR-7	3.7	0.90
PR-12	5.95	3.10
KPR-102 (Krypton)	2.40	1.30
HPR-50 (Halogen)	5.20	6.76
HPR-52 (Halogen)	2.80	2.78

Table 2 Xenon Bulbs

Flashlight Models	Bulb MSCP	Bulb Lumens
41-3610	3.18	40
41-3630	7.2	90
41-1375	3.18	40
41-1775	3.98	50
41-2510	3.18	40

Beam candlepower is the luminous intensity, or brightness, measured in the parallel light beam projected by the flashlight. It is a quantity advertised by many flashlight manufacturers. Other flashlight manufacturers do not publicize beam candlepower for their flashlights nor do they test their flashlights to any particular test specification. There are flashlight specifications that state how a flashlight can be tested. MIL-F-3747E, the specification for standard military flashlights used by marine inspectors, specifies that when the flashlight lens is located 5 feet from a screen, the spot of light on the screen shall be between 5 and 11 inches in diameter. ASTM F-1014-86 also specifies that a flashlight must project a concentrated beam of light not less than 5 inches or more than 11 inches in diameter when located 5 feet from a screen. MIL-F-3747E also requires that the parabolic reflector have a minimum coefficient of reflection of 75 and that the lens must transmit 83 percent of the light. The light output of the flashlight is governed by these requirements and the bulb used. There are no minimum beam candlepower

requirements. The best direct comparison that can be made is the lamp MSCP values in Table 1.

Federal Specification W-F-00421(GSA-FSS) requires that flashlights be tested at 10 feet from the screen. Minimum candlepower requirements are listed for measurements taken around a 4 inch and an 8 inch diameter circle centered on the spot of light on the screen. The on and off times for the flashlight are also specified. This seems to be the most complete specification. The plane of the screen must be perpendicular to the optical axis of the flashlight in each of these tests.

When some flashlight manufacturers were questioned as to whether they test their flashlights according to any of the above specifications or any industry recognized method of testing, they claimed that they do not test their flashlights to any standard. The vendors who publish a beam candlepower in their literature could not state how they arrived at the beam candlepower numbers. Some manufacturers test their flashlights with a power supply to keep the flashlight's voltage constant.

Bright Star Industries pointed out that the beam candlepower in a flashlight depends upon the age and type of batteries, bulb type and bulb location in the reflector, the reflector style and how the flashlight is designed. When a flashlight is new it produces the maximum candlepower, but after the lens becomes dirty and the batteries weaker the candlepower diminishes. For a beam candlepower measurement to be useful, the distance from the source at which the measurement was made must be given. The beam candlepower numbers published by most vendors do not have a corresponding distance associated with the candlepower.

Eveready Battery Company, Incorporated does not publish flashlight beam candlepower. Their engineer stated that in the past they have tried to measure the spot of light from a flashlight beam at a 10 foot distance, but they have difficulties because the brightness varies dramatically within the beam. The brightness in the light has imperfections and blotches of darkness due to the bulb's filament. They compare the brightness in their flashlights by which bulb is used in them.

Table 3 compares many of the flashlights that are available on the market. The beam candlepower shown in the charts is an advertised maximum value. The beam of light could have been measured at a distance of 5 inches or 10 feet or some other distance. Few vendors will state what distance is used. Tables 4 and 5 compare headlamps and personal lights. Personal lights are designed to be hung around the neck.

Table 3 Typical Flashlights

	FLASHLIGHT						
	VENDORS						
	Koehler Mfg.	Koehler Mfg.	Streamlight Inc.	Streamlight Inc.	Streamlight Inc.	Bright Star Ind.	Bright Star Ind.
Model	8400M	8400T	SL-20X	SL-35X	SL-15X	2117	2124
Maximum Candlepower	25,000	25,000	30,000	40,000	20,000	Not available	Not available
Bulb	Halogen/HPR50	Halogen/HPR50	Quartz-Halogen	Quartz-Halogen	Halogen	PR-6	PR-3
Battery	4 "C" Alkaline	4 "C" Alkaline	Rechargeable Nickel-Cadmium	Rechargeable Nickel-Cadmium	Rechargeable Nickel-Cadmium	2 "D" Cell	3 "D" Cell
Light per Charge (Hours)			1.5	1.5	1.5		
Weight	15 oz.	15 oz.	1.9 lbs.	2.8 lbs.	1.0 lbs	6.6 oz. w/o batteries	8 oz. w/o batteries
Approval		Factory Mutual and Coast Guard				MSHA.UL.CSA and ASTM Type II	MSHA.UL.CSA and ASTM Type II
Price	$ 31.45	$ 31.45	$ 175.00	$ 205.00	$ 127.00	$ 3.98	$ 4.54
Features	Wide beam reflector and Waterproof		Variable Intensity Module	Variable Intensity Module	Floatable and Variable Intensity Module	Circuit breaker protection	Circuit breaker protection

Table 3 Typical Flashlights (Continued)

	FLASHLIGHT						
	VENDORS						
	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star 'nd.	Bright Star Ind.
Model	2217	2220	2224	1819	1826	2619	2626
Maximum Candlepower	Not available	Not available	Not available	Not available	Not available	Not available	Not available
Bulb Type	PR-6	PR-6	PR-3	PR-2	PR-3	PR-2	PR-3
Battery Type	2 "D" Cell	2 "D" Cell	3 "D" Cell	2 "D" Cell	3 "D" Cell	2 "D" Cell	3 "D" Cell
Light per Charge (Hours)							
Weight	6.6 oz. w/o batteries	6.6 oz. w/o batteries	8 oz. w/o batteries	6.6 oz. w/o batteries	8 oz. w/o batteries	5.3 oz. w/o batteries	5.3 oz. w/o batteries
Approval	MSHA,UL,CSA and ASTM Type II	MSHA,UL and CSA	MSHA,UL,CSA and ASTM Type III	None	None	None	None
Price	$ 4.76	$ 6.10	$ 5.20	$ 4.20	$ 4.58	$ 2.38	$ 3.14
Features	Circuit breaker protection, 3-way switch and waterproof	Circuit breaker protection, 3-way switch and waterproof	Circuit breaker protection, 3-way switch and waterproof	Waterproof and 3-way switch	Waterproof and 3-way switch		

Table 3 Typical Flashlights (Continued)

	FLASHLIGHT						
	VENDORS						
	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.	Bright Star Ind.
Model	6900	1925	RBR 20G	8702	8120	3120	801
Maximum Candlepower	Not available	Not available	Not available	Not available	Not available	Not available	Not available
Bulb Type	PR-12	PR-7	KPR-102	KPR-102	PR-6	PR-3	PR-6
Battery Type	5 "D" Cell	3 "D" Cell	2 "D" Cell	2 "D" Cell	Nickel Cadmium 2 Cell	Nickel Cadmium 3 Cell	Nickel Cadmium 2 Cell
Light per Charge (Hours)							
Weight	16 oz. w/o batteries	8 oz. w/o batteries	5.3 oz. w/o batteries	5.3 oz. w/o batteries	16 oz. w/o batteries	1.3 lb w/o batteries	13.3 oz. w/o batteries
Approval	None	ASTM Type I	None	None	UL	UL	UL
Price	$ 10.47	$ 5.30	$ 3.80	$ 1.85	$ 14.96	$ 22.10	$ 14.00
Features	3-way switch	Waterproof, 3-way switch and Tuflexx lens	Thermoplastic rubber body	High density polyethylene body	120 VAC rechargeable	120 VAC rechargeable	12 VDC rechargeable

Table 3 Typical Flashlights (Continued)

	FLASHLIGHT						
	VENDORS						
	Bright Star Ind.	Bright Star Ind.	Stuart R. Browne Mfg. Co.	Stuart R. Browne Mfg. Co.	Stuart R. Browne Mfg. Co.	Stuart R. Browne Mfg. Co.	Mag Instruments, Inc.
Model	501	301	F10X	F30X	F81X	F91X	S2D016
Maximum Candlepower	Not available	Not available	Not available	Not available	Not available	Not available	9000 at 5 FT
Bulb Type	Halogen	PR-3	PR-2	PR-3	PR-2 or PR-6	PR-3	Krypton
Battery Type	Nickel Cacmium 5 Cell	Nickel Cadmium 3 Cell	2 Cell	3 Cell	2 Cell	3 Cell	2 "D" Cell
Light per Charge (Hours)							
Weight	2 lb w/o batteries	1.2 lb w/o batteries	16 oz. w/o batteries	16 oz. w/o batteries	16 oz. w/o batteries	16 oz. w/o batteries	15 oz w/o batteries.
Approval	UL	UL	CSA and UL	CSA and UL	Mil-F-3747E, CSA and UL	Mil-F-3747E, CSA and UL	None
Price	$ 36.75	$ 21.55	$ 5.25	$ 6.60	$ 8.10	$ 8.60	$ 30.00
Features	12 VDC rechargeable	12 VDC rechargeable	Polypropylene case	Polypropylene case	Tuffite case	Tuffite case	

Table 3 Typical Flashlights (Continued)

	FLASHLIGHT						
	VENDORS						
	Mag Instruments, Inc.	Mag Instruments, Inc.	Mag Instruments, Inc.	Mag Instruments, Inc.	Dorcy International	Dorcy International	Dorcy International
Model	S3D016	S4D016	S5D016	S6D016	41-3610	41-3630	41-1375
Maximum Candlepower	14,000 at 5 FT	15,700 at 5 FT	17,000 at 5 FT	20,500 at 5 FT	Not available	Not available	Not available
Bulb Type	Krypton	Krypton	Krypton	Krypton	Xenon	Xenon	Xenon
Battery Type	3 "D" Cell	4 "D" Cell	5 "D" Cell	6 "D" Cell	2 "D" Cell	5 "D" Cell	2 "D" Cell
Light per Charge (Hours)							
Weight	18 oz w/o batteries	20 oz w/o batteries	22.5 oz w/o batteries	25 oz w/o batteries	14 oz w/o batteries	19 oz w/o batteries	6.5 oz w/o batteries
Approval	None	None	None	None	None	None	None
Price	$ 31.00	$ 32.00	$ 33.00	$ 36.00	$ 12.00	$ 14.75	$ 2.65
Features					Aluminum body and Adjustable lens	Aluminum body and Adjustable lens	

Table 3 Typical Flashlights (Continued)

	FLASHLIGHT						
	VENDORS						
	Dorcy International	Dorcy International	Fulton Industries, Inc.	Fulton Industries, Inc.	Fulton Industries, Inc.	Fulton Industries, Inc.	Fulton Industries, Inc.
Model	41-1775	41-2745	903/901	918N	93	911	N35
Maximum Candlepower	Not available	Not available	Not available	Not available	Not available	Not available	Not available
Bulb Type	Xenon	Xenon	PR-6	Krypton	PR-6 or Krypton	PR-3	PR-3
Battery Type	3 "D" Cell	3 "D" Cell	2 "D" Cell	2 "D" Cell	2 "D" Cell	2 "D" Cell	2 "D" Cell
Light per Charge (Hours)							
Weight	7.6 oz w/o batteries	16 oz w/o batteries	6.7 oz w/o batteries	6.7 oz w/o batteries	6.7 oz w/o batteries	8 oz w/o batteries	8 oz w/o batteries
Approval	None	None	None	None	U.S Government standard	Class II Group G and Class I Group C and D. U.L. and MSHA.	Class I Group C and D. U.L. and MSHA
Price	$ 3.50	$ 3.50	$ 3.21 (903) $ 2.81 (901)	$ 2.77	$ 4.59	$ 4.44	$ 5.67
Features			Shock and corrosion resistant. with flood reflector (903) or parabolic reflector (901), focused beam.	Shock and corrosion resistant with flood and parablolic reflectors available	Waterproof and polypropylene body. Same features as 900 series.	Waterproof and circuit breaker protection	ABS body, Waterproof and circuit breaker protection

Table 4 Typical Headlamps

	HEADLAMP					
	VENDORS					
	Bright Star Ind.	Bright Star Ind.	Streamlight Inc.	Koehler Mfg.	Koehler Mfg.	Fulton Industries, Inc.
Model	3550	8750	TopSpot	5100-G7	5200-G7	14KB-CS
Maximum Candlepower	Not available	Not available	Not available	15,000	15,000	Not available
Bulb Type	PR-3	KPR-102	Krypton	Xenon	Xenon	Krypton/K-2
Battery Type	3 "D" Cell	2 "C" Cell	4 "AA" Cell	DC Rechargeable lead acid	AC Rechargeable lead acid	2 "C" Cell
Light per Charge (Hours)			Not available	14	14	
Weight	9.3 w/o batteries	3.3 w/o batteries	7.9 oz.	5 lb. 7 oz.	5 lb. 7 oz.	8 oz w/o batteries
Approval	None	None	None	MSHA	MSHA	None
Price	$ 4.85	$ 2.95	$ 32.45	$ 178.00	$ 162.00	$ 5.49
Features	Non-conductive, lightweight and battery case with belt clip	Chemical resistant polypropylene body, lightweight and velcro to hardhat.	Fits head or hat and converts into flashlight.	Focusable bulb	Focusable bulb	Wide angle reflector, water resistant and stretch headband.

Table 5 Typical Personal Flashlights

	PERSONAL FLASHLIGHT		
	VENDORS		
	Streamlight Inc.	Koehler Mfg.	Koehler Mfg.
Model	SL-90X	100-X	100-D
Maximum Candlepower	16,000 to 19,000	30,000	30,000
Bulb Type	Halogen	Halogen	Halogen
Battery Type	Rechargeable Nickel Cadmium	Rechargeable Lead Acid	Rechargeable Lead Acid
Light per Charge (Hours)	1.5	3.5	1.75
Weight	16 oz	1 lb 14 oz	18 oz
Approval	Factory Mutual	Factory Mutual	Factory Mutual
Price	$ 180.00	$ 93.00	$ 90.00
Features	2.5 foot diameter circle at 20 feet	Focusable	Focusable

To summarize, though beam candlepower values are available for some flashlights, brightness can't be compared because there is no common test specification used by the vendors. The candlepower information that is published does not give the buyer enough information.

The best method for comparing flashlights would be to purchase several copies of each flashlights and to test them in a light tunnel to simulate the conditions the inspectors would encounter onboard ships. This requires testing at greater distances from the lens than the current standards consider. Better flashlights would be of great benefit to marine inspectors and the cost to test existing flashlights would be money well spent. These tests could result in the Coast Guard developing its own specification for flashlights for marine inspectors.

5.2.2 Telescopic Aids

One method for viewing the portions of a vessel's spaces where access for close viewing is not available is a telescopic vision device. These could include binoculars, telescopes, and telephoto lens on cameras. Telescopic aids provide a close up view of the structure with the inspector standing on the bottom or other platform. These devices are limited in their field of view and can only show areas that are not blocked by other structure. Nevertheless, they offer an inexpensive means to greatly expand the amount of structure that an inspector can inspect, "close up."

Several rugged models of binoculars are available on the market and some have already been used by marine inspectors. A suitable pair of zoom binoculars costs about $200. The major problem as with any magnification device is adequate lighting. It is difficult to use the binoculars while simultaneously trying to aim a flashlight on the area. And the intensity of lighting varies as the square of the distance from the source. Thus, very strong lights are needed to provide adequate illumination.

Powerful halogen head lamps are available that could be used in conjunction with binoculars or telescopes to provide illumination at the spot being inspected. This frees the inspector's hands for the binoculars, but practice is needed to coordinate the light and the binoculars. Binoculars could easily be developed with an attached light. This light could be designed to illuminate the field of view of the binoculars. Doing this would add some weight to the binoculars which could cause fatigue with frequen .ise.

A test of binoculars is recommended. Various types having different optical quality, magnification, and field of view could be tried under typical field conditions to determine the best combination of parameters to use. Binoculars could be tested with various lights attached to determine if such a concept is worth pursuing. A good set of binoculars with attached lighting would be a valuable addition to the inspectors tools.

5.2.3 Borescopes and Endoscopes

Borescopes and endoscopes are designed to extend the inspector's eyes into areas where it is impossible to get access to because of the small size of the space. A borescope is a precise optical instrument with built-in illumination as shown in Figure 3. The endoscope is much like a borescope except it has a superior optical system and a high-intensity light source. Both have limited uses in structural inspections. One such application might be a small box-like structure that is too small for internal examination by other visual means. Borescopes and endoscopes are available in many sizes and magnifications. They are expensive due to the precision required in their manufacture but cost almost nothing to use. They can be used with minimal training by anyone already trained in other aspects of visual inspection.

If needed, these devices are readily available. Because they are infrequently used, the Coast Guard should not spend effort to improve this type of inspection techniques.

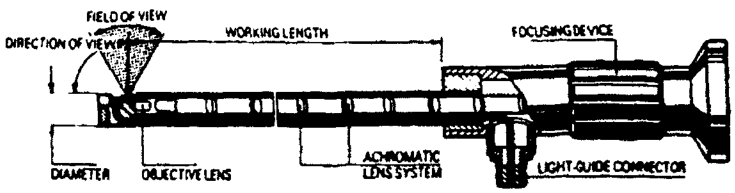


Figure 3 Typical Borescope Design

5.2.4 Remote Video

Access to the overhead and upper structure on bulkheads is lacking in many spaces. It could be more convenient to move a video camera to these areas than it is to move a human. Robot arms or remotely operated vehicles in flooded tanks could be used to gain access. Telescopic lenses can be used to minimize the need to move the camera. Remote video provides nearly as good a view as human eyes but the stereoscopic view provided by direct viewing is lost unless special 3-D video systems are used. Also, the resolution on a monitor, even a very good one, is less than direct viewing provides. One of the chief drawbacks of any remote video inspection is maintaining the inspector's concentration on the screen. If the camera is scanning an area, even a moment's lack of attention may result in missed defects. When an inspector scans an area visually, repeated passes over an area are usually made, often subconsciously. The camera must be told to repeat the scan of an area.

Figure 4 shows a typical camera size available today although smaller cameras are available. A typical mono video system proposed by Connecticut Analytical Corporation utilizes a color Charge-Coupled-Device (CCD) camera, a zoom lens and a high intensity illumination source parallel to the camera lens. The camera and light are mounted on a motor driven turntable capable of 0° - 360° rotation with an integral 0° - 90° axis drive head. The camera unit has a tether line attached to the power supply and control panel. The control panel incorporates user controls and indication of camera position, zoom and illumination. A color monitor and video tape recorder complete the system. The system is made rugged enough for use in the tank environment. The equipment necessary to put the package together is available commercially.

Figure 4 Typical Mini Camera Size

A system like that described above can be prototyped for approximately $49,000 which does not include the

robotic arm or other movement device. The cost includes designing all equipment to be corrosion resistant.

Stereo video systems are available on the market. These typically consist of a pair of standard video cameras mounted together a fixed distance apart with a common focus at a fixed distance from the cameras. The two images are processed by a special view/record controller and playback controller. These put both camera images on the monitor alternately at double the normal scan rate. The viewer needs special glasses to separate the alternating images, one image for the right and one for the left eye. StereoGraphics Corporation has developed a liquid crystal shuttering system where the lens of the glasses are rapidly made opaque or clear in synchronization with the signals on the monitor. An infrared signal from the monitor keeps the glasses synchronized with the picture viewed. The images from the two cameras can also be projected on a screen through polarizing filters and viewed with special polarized glasses. One lens is polarized for horizontal and one for vertical to separate the images. The record and playback equipment for stereo viewing costs about $14,000. The cost of dual cameras starts at about $5,000 but will likely cost more if telephoto lens and rugged construction is desired. Additional camera controls may be needed that are not covered in the above costs.

Except for the need to wear special glasses while viewing, mono and stereo systems are similar in operation. Operating costs for video systems are small although the cost to place a robotic arm or ROV in position could be substantial. Coast Guard inspectors could learn to use a remote video system with only a few hours training.

In operation, the camera pod could be mounted on some device, such as a robotic arm, to move it to different locations in the space being inspected. The inspector would operate the camera and light from the control panel located on deck (up to 140' distant). The operator could pan the camera using a joystick or rotary controls with the exact camera orientation displayed on a video monitor. Detailed examinations could be performed using the zoom capabilities for locations where the camera can not be moved close. The entire inspection could be recorded to videotape with voice comments included for future review. Since the total inspection may be hampered by visual obstructions of the internal structural frames, the system may need to be relocated to other access ports to get a total view. In a centerline tank, which typically has framing only on the bottom and overhead, coverage is limited primarily by the distance from the camera to the object viewed. Even here, the best view of framing is obtained by moving the camera to locations near the frames, say within 30 feet maximum. This corresponds to the spacing of tank cleaning openings on small tankers. On large tankers, those with permanently installed tank cleaning systems, only a few access and ullage trunks may be available for the camera. In wing tanks, deep web frames are normally positioned 10 to 20 feet apart. The camera needs to be lowered into each of the bays between web frames to provide full coverage. On a typical tank there are 10 to 20 such bays. Thus, inspecting wing tanks with a camera is so time consuming that it is not very practical. Also, appropriate deck openings may not be present in each frame bay.

Camera systems do have many desirable features for marine inspection. First and foremost, they allow the inspector to remain outside the tank and free from the hazards of tank entry. Another advantage is that cameras allow for inspection of large areas in a short amount of time once the system is set up. Third, cameras provide a videotape record which can be reviewed at a later time and notes or a report can be written later. This allows the inspector to concentrate more on the actual inspection.

Remote video systems are not without limitations, some of which are mentioned above. One hundred percent viewing of a space is not possible due to the complexity of the structure. Some of the structure is always blocked by nearby structure. In addition, the video image is a two dimensional picture of a three dimensional structure. This makes it more difficult to pick out damage or flaws. Vibrations of the camera reduce the video quality especially when using magnification. Moving the camera from opening to opening could prove to be quite time consuming since the monitor and controls must be moved also. Before employing any remote video equipment, experimentation with the ease of operation, video quality and lighting should be conducted.

Video systems may make inspection possible in some circumstances where it is not safe to enter a tank. Generally, this technique is expensive, complicated, and likely to result in a lower quality inspection than visual inspection from within the tank. Further development is not recommended.

5.2.5 Night Vision Devices

Visual inspection is often difficult in the ship environment. Very little ambient light enters tanks and the little that does enter is absorbed by the dark colors of the ship bulkheads. Night vision equipment allows viewing at low light levels using the visible and near infrared regions of the spectrum. An artificial source of light is not required and many systems present a useable image when an illumination equivalent to starlight is available.

Typically, the low light image is incident upon a fiber optic faceplate and is transmitted to a photo cathode where the photon image is converted into an electronic one. The electronic image can then be amplified to the brightness desired. Recent developments have made it possible to digitize the output image and reproduce it on a video monitor. The principal area of concern with night vision devices is whether the resolution is adequate for detecting cracks and other small defects.

Night vision devices have many of the drawbacks of remote video systems. The devices provide a two dimensional view although the use of twin detectors on a helmet may eliminate most of this problem. In addition, the view is monochrome. Color night vision devices are not available. Nevertheless, a telescopic night vision device could provide an inspector with enhanced capabilities at a reasonable cost, less than $6,000.

The following devices are typical. The Varo Model 2000 (ANVIS) is a helmet mounted type of night vision goggle which weighs about 1.25 pounds, as shown in Figure 5. It allows the user to view objects from ranges of 11 inches to infinity. The goggles can be suspended from a neck cord when removed. However, the goggles are easily damaged and may not be rugged enough for marine inspection use. Another night vision device is the NVEC 500/520 pocketscope shown in Figure 6. This is a single lens, combination hand-held viewer and camera lens system. This unit weighs less than a pound and used 2-"AA" batteries. The eyepiece can also mate directly to popular 35mm SLR cameras and camcorders using a 55mm step up ring.

Figure 5 Helmet Mounted Night Vision Device

Night vision devices are available in the two basic types illustrated: night vision goggles, which fit over the face and the night vision pocketscope, which can be used as a hand held viewer or as a camera night-lens system. The inspector could use either type to inspect the inside of a tanker, with the illumination from one tank cleaning opening. The illumination available from one 12.5 inch tank cleaning opening for a center tank of a 70,000 d.w.t., on an overcast day, is approximately 0.1 footcandles. This is equivalent to the amount of illumination in a theatre during a movie.

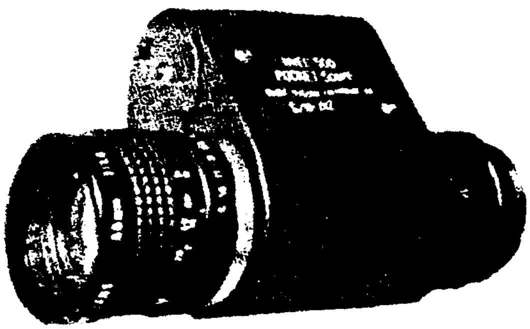


Figure 6 Night Vision Pocketscope

Night Vision Goggles

Night vision goggles are built according to military specification and several manufacturers produce night vision goggles according to the specification. Table 6 gives the principal features of night vision goggles. In Table 6, the AN/PVS designation is the military specification for each goggle.

Both ITT Defense and Night Vision Equipment Company manufacture the AN/PVS-5C. The image intensifier tube used in this goggle is the Generation II. This tube has been improved over older versions to provide better resistance to the humidity, increased range and improved

Table 6 Characteristics of Typical Night Vision Goggles

Model	AN/PVS-5C	AN/PVS-7B
Type	Generation II	Generation III
Scene Illumination	10^{-6} to 1 footcandles	10^{-6} to 1 footcandles
Spectral Response	Visible to .86 microns (IR)	Visible to .90 microns (IR)
Field of View	40 deg.	40 deg.
Magnification	Unity	Unity
Brightness Gain	400 fl/fl, min.	2,000 fl/fl, min.
Focus Range	25 cm to infinity	25 cm to infinity
Voltage Required	2.7 to 3.0 VDC, battery	2.7 to 3.0 VDC, battery
Battery Type	2 "AA"	2 "AA"
Battery Life	40 Hours	50 Plus Hours
Weight	907 grams	680 grams
Operating Temperature Range	-45 C to +45 C	-51 C to +45 C
Humidity	0 to 95%	0 to 95%
Immersibility	1 meter	1 meter
List Price	$ 5,130.00	$ 5,495.00

low-light-level performance. Some of the features of the AN/PVS-5C include an automatic high-light cutoff feature that protects the image intensifiers by shutting off the power when the goggles are exposed to prolonged high light levels. A low-intensity infrared light source is built into the system for suplemental illumination that allows map reading and other short-range tasks. This goggle operates within a scene illumination range of 10^{-6} to 1 footcandle. As previously estimated the illumination inside of typical tank is 0.1 footcandle, which falls within this range. The tube life of the Generation II tube is 2,000 hours.

The AN/PVS-7B is also manufactured by ITT Defense and Night Vision Equipment Company. This goggle has the best image intensifier tube available, which is the Generation III. This tube is hermetically sealed. The Generation III tube provides improved resolution , tripled photosensitivity and double the luminous gain as compared to the Generation II tube. This tube extends operation into the near infrared region of the spectrum where night light is more abundant and the contrasts are higher. The AN/PVS-7B allows the user to see at starlight levels and below and to see objects not visible to Generation II devices. The tube life of the Generation III tube has been increased to 7,500 hours. Features included in this goggle are an IR-on indicator, an automatic high-light cutoff to protect the image intensifier, and a low voltage indicator.

Night Vision Pocketscope

Night Vision Equipment Company manufactures two pocketscope, one incorporates the Generation II image intensifier tube and the other scope has the Generation III tube. Features of the night vision pockescopes are listed in Table 7. ITT Defense and Varo Incorporated offer a comparable pocketscope to that built by Night Vision Equipment Company. These pocketscope's can be used on 35mm cameras, closed circuit TV, and Camcorders. They also function as handheld viewers. Included in these scopes is an Automatic Brightness Control (ABC) and a bright-source protection system (BSP). The ABC maintains uniform image illumination when viewing during changing light conditions. The BSP protects the photocathode during exposure to high levels of light. A built in low-level infrared light source permits map reading and viewing where ambient visible light and low infrared signals are not available. The

Table 7 Hand Held Night Vision Devices

Model	500	600
Type	Generation II	Generation III
Spectral Response	Visible to infrared	Visible to near-infrared
Field of View	40 deg. at 1X	40 deg. at 1X
Magnification	1X,2X or 3X	1X, 2X or 3X
Brightness Gain	7,000 min./ 15,000 max.	20,000 to 35,000
Focus Range	61 cm to infinity	45 cm to infinity at 1X
Voltage Required	3 Vdc battery	3 Vdc battery
Battery Type	2 "AA"	2 "AA"
Battery Life	40 hours	40 hours
Weight	425 grams	w/ 1X lens 450 grams
Operating Temp. Range	-54 C to +46 C	-54 C to +46 C
Humidity	0 to 98 %	0 to 98 %
List Price	$ 2,995.00	$ 5,495.00

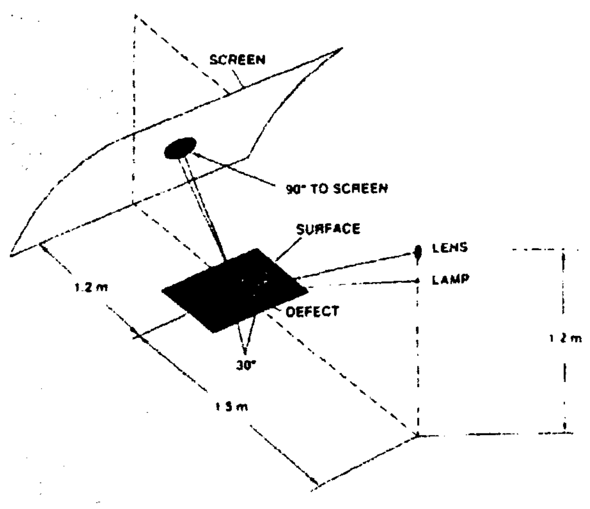


Figure 7 D-Sight Setup

housing on the scope is made out of Noryl, making it resistant to rust, dents and scratches.

Cost per use and training are minimal. Before employing any night vision device, the specific device should be tested by inspectors for image quality, ruggedness, and personal comfort. Night vision devices show promise for overcoming the low light conditions present in cargo tanks and are worth further investigation by the Coast Guard. Of particular importance is whether or not these devices have the ability to show small defects such as cracks.

5.2.6 Diffracto Sight (D-Sight)

D-Sight is a new surface inspection technique. It is a simple optical arrangement involving a source of light and a retro-reflective screen as shown in Figure 7. The technique is used for visualizing surface distortions, depressions, or protrusions and is adaptable to the detection of any phenomenon leading to a change in surface topography greater than 10 μm. This includes corrosion under paint films and stress cracks. D-Sight is a real-time technique with particular application for the rapid inspection of large surface areas (up to 80 m^2/hr). More area can be inspected per hour if the size of discontinuities sought is larger. In its basic configuration, the technique could be used directly as an enhancement to visual inspection. It has the potential of being automated through the use of computer vision techniques.

The optical setup for D-Sight consists of a light source, a retro-reflective screen, and the object being

inspected. The surface being inspected must be reflective; however, rough surfaces can be made reflective by wetting with a fluid.

The light from the source is first reflected by the inspected surface. It then strikes the retro-reflective screen. The retro-reflective screen attempts to return all these rays to the initial reflection point on the inspected surface. However, the screen, which consists of numerous silvered glass beads (25-75 μm dia), returns a cone of light to the surface, not a single ray. This characteristic of the retro-reflective screen creates the D-Sight effect. As shown in Figure 7, the imaging lens or the observers's eye is offset from the light source. When a perfectly flat surface is observed in the D-Sight setup, uniform light intensity is observed over the surface. The intensity of the light depends on the offset of the imaging lens - the smaller the offset, the higher the intensity. The change of intensity is fairly rapid with the change in the offset angle. If a wavy surface is observed at a fixed offset angle, the slope of a surface wave will appear either brighter or darker. The D-Sight process can therefore be viewed as a slope-detecting technique, with positive surface slopes looking dark and negative slopes looking bright relative to the background.

In metallic aircraft structures, D-Sight has been shown to be capable of detecting cold-worked holes, corrosion, and fatigue cracks associated with high stress-intensity factors. Limited inspections of an unpressurized commuter aircraft and of an aging pressurized airliner have demonstrated the potential of the technique. Figure 8, from reference 8, demonstrates the ability of D-Sight to enhance surface discontinuities. Figure 9, from the same source, shows how cracks are highlighted by use of D-Sight.

The technique could be adapted in the near term for the regular inspection of ship plating for corrosion and cracking. It would be particularly useful for detection of exterior hull cracks if used outside the ships hull. In this application there is no intervening structure to interfere with the technique. Damage caused by groundings or collisions could be readily detected and a concentrated interior inspection of the affected zone could be made. Corrosion could be detected from any angle of view but cracks are most easily detected when they lie across the viewing plane, not in line with the light rays. Thus, inspection from two positions, 90 degrees apart, may be needed to find all cracks. The procedure could be automated if a means is provided to move the apparatus over the hull while taking video photos of the inspection zone. An apparatus for inspection of areas larger than 80 m^2/hr should be possible but small cracks are likely to be missed.

Inside the ship the technique could be used to view the plating between longitudinals or the stiffeners themselves. The amount of area that could be viewed with a single setup is limited within the ship and the apparatus would need to be moved frequently.

Initial setup time of D-Sight equipment is estimated at 10 minutes. Subsequent setup time for moving to an adjacent location is about 4 minutes. Inspection of a highlighted area takes place in the time it takes the inspector to visually scan the highlighted area. The size of the area highlighted depends on the retrospective screen size, a 5' x 5' screen highlights an area 4' x 4'.

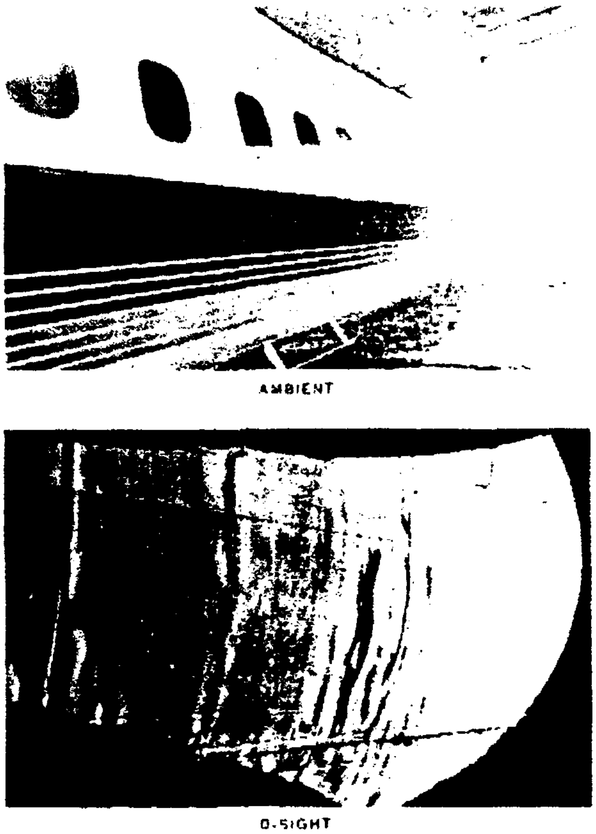


Figure 8 Center Fuselage Section of a Commuter Aircraft

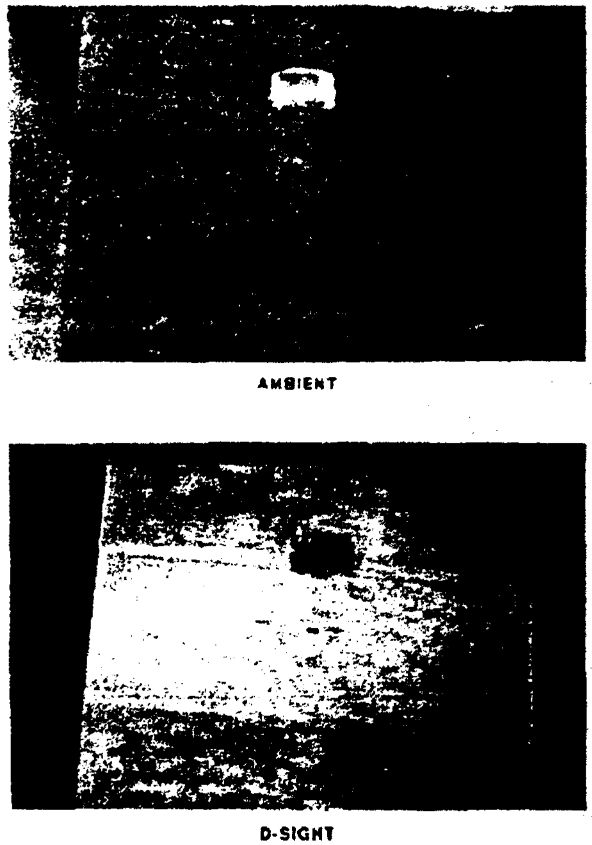


Figure 9 3mm Thick Aluminum with Fatigue Cracks

An 8' x 8' screen highlights a 6' x 7' area. The same light source is used for both. A small amount of training in system setup is needed but no additional inspection training is required. Initial cost for a D-Sight system is about \$15,000 to \$16,000 for a handheld system without a camera. Cost per use is negligible. If an automated system is developed, the cost per use would depend on the complexity of the equipment used to move the D-Sight apparatus between locations and to record the resulting images.

This appears to be a promising technique for inspecting relatively large areas rapidly. However, it has not been used for shipboard applications and some development effort is needed. The best equipment for use in marine inspection still needs to be evaluated.

5.3 Dye Penetrant

This is a very simple method commonly used to visually enhance surface cracks and is one of the standard NDT techniques used in industry. First, the surface must be thoroughly cleaned. A solution of penetrant is then sprayed on the suspect surface area and is absorbed into

the cracks. Excess penetrant is wiped or washed from the surface and a developer is applied to the area to draw out the dye. The crack will show up as a visual indication. Depending on the penetrant used, the crack can be viewed in either visible or ultraviolet light.

One of the first applications of penetrant testing might be used today on an oil tanker. In this early application, parts were first soaked in a mixture of used oil and kerosene. After the surface penetrant was removed, the part was covered with whiting (a mixture of chalk and alcohol). The remaining penetrant in cracks would wet the whiting. The first step in this process has already occurred on the oil tanker. Cleaning and coating with a modern substitute for whiting might be a quick way to locate cracks.

While the basic penetrant testing process is simple enough to learn in perhaps 5 minutes, The *Nondestructive Testing Handbook*, reference 11, includes 594 pages of discussion of the problems and precautions related to this inspection tool. Penetrant inspection is fraught with the largest number of difficult-to-control variables of any of the common nondestructive testing methods. The demands of observation, process control, discrimination, and knowledge of materials and processes are greater for a penetrant inspector than for an operator in any other common NDT method. Determining whether or not a penetrant indication is a defect requires as much judgement and investigation as does reading a radiographic film to determine if an indication does or does not represent a flaw.

Perhaps the most difficult phase of the process to control is penetrant removal - washing adequately to remove excess penetrant but not so excessively as to remove the penetrant from the flaws. Complex shaped parts are nearly impossible to wash uniformly. Otherwise satisfactory penetrant materials can be misused by contaminating the penetrant with water or dirt. Improper concentration and mixing of developers can also cause faulty indications.

Two other variables that frequently result in flaws being missed are prior use of incompatible penetrants and material removal prior to penetrant inspection. Grinders and welders sometimes use a red visible penetrant to verify removal of welding flaws. When a certified inspector uses a fluorescent penetrant later to verify flaw removal, the odds are against detecting a remaining flaw that was not completely removed. The flaw becomes filled with the visible penetrant and smeared over during the metal removal operation. Abrasive cleaning and other metal removal methods alone can completely hide a flaw from detection by penetrants.

Using the penetrant technique an inspector would spend approximately 1 hour for 2 feet of weld. Dye penetrant kits are commercially available for about $150.00. This kit includes everything necessary to perform an inspection, and one kit will cover 50 feet of weld. This method is simple, inexpensive, easy to perform and requires no bulky equipment, however, it is only good for inspecting small areas where surface cracks are suspect. It is not a practical application for inspecting large areas quickly. The Coast Guard should continue to rely on using qualified inspectors hired by the owners for penetrant dye inspections.

5.4 Ultrasonics

Ultrasonic thickness gaging is the most widely used technique for determining the plate thickness of steel structures. It is one of the few methods that can be applied underwater as well as on dry surfaces. Measurement of steel wall thickness is normally done using ultrasonic pulse-echo compression wave techniques and equipment. A pulse of ultrasound is generated in a crystal, passed into the steel surface and reflects from the back wall. The time delay (t) between the input pulse and the return echo from the back wall can be measured, and the wall thickness can be determined using the appropriate value of ultrasound velocity (V) for the material: wall thickness = $(t \times V)/2$. The instruments require that the steel surface be clean and smooth, and a couplant such as water or a gel is used to ensure a good transfer of energy. Application of ultrasonics for spot checking of plate thickness can be done with a hand-held digital instrument such as the one shown in Figure 10. There are a number of commercially available instruments on the market for marine inspection use. The initial cost of the instrument ranges from $1,000 to $4,000 depending on the sophistication and the number of accessories desired. For example, some can be connected to a printer or a plotter to obtain a hard-copy record of all measurements. Some will supply a statistical analysis of the areas inspected. The instruments are all easy to use and come with an operating manual. A single reading can be taken instantaneously.

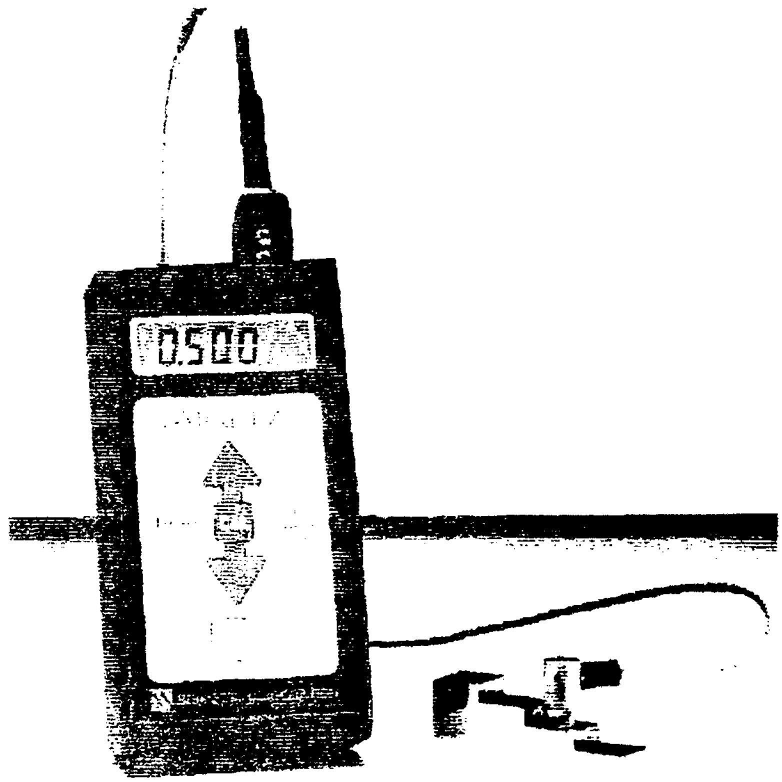


Figure 10 Hand-held Ultrasonic Thickness Gauge

The accuracy of a single ultrasonic measurement is a function of the equipment accuracy and operator technique in using that equipment. Under the best conditions there is a 95% chance that the true thickness is within a range of $\pm$ 0.5mm from the measured thickness. However, the accuracy can be improved if the instrument is calibrated before use using a known thickness of the same material being tested. Commercial step-block calibration standards are available for this purpose in various base metals.

The digital instruments are suitable for spot checks, usually in a predetermined array covering a large surface such as a bulkhead. A full picture of plating thickness is not provided

by this method. Local corrosion problems may be missed. Multi-probe scanners can be used if thickness measurements over the whole plate are required. Multiple probe scanners are discussed in the next section.

Digital ultrasonic instruments only provide what the instrument thinks is the time between the source signal and the return signal from the back wall. If a flaw or inclusion in the plate

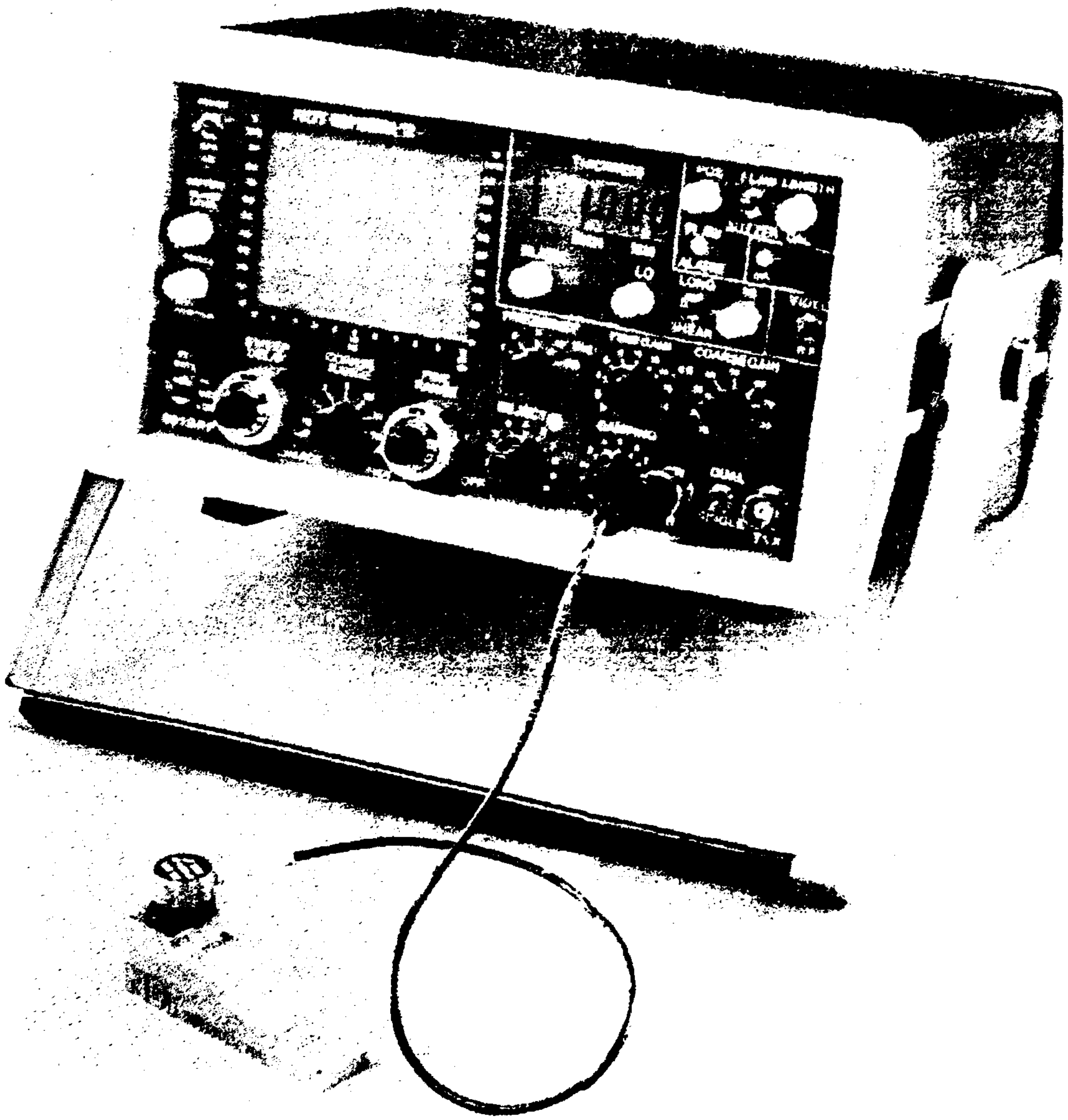


Figure 11 Oscilloscope Based Ultrasonic Thickness Gauge

reflects the signal, the digital instrument will report the distance to the flaw as the plate thickness. The operator has no control over :his and may not recognize what is occurring. A better means of conducting spot surveys uses 'A'-scan oscilloscope ultrasonic equipment similar to the type shown in Figure 11. These instruments have a built-in oscilloscope and require a higher degree of skill to calibrate and interpret the image. On the oscilloscope, the operator can see the various signals reflected back to the sensor and determine which is the correct back wall reflection. The thickness of the plating is determined from the time between signal peaks on the oscilloscope. The results are more accurate as a result. Also, internal flaws are more likely to be uncovered by this equipment. An oscilloscope equipped ultrasonic tester and associated equipment costs about $1,700 to $2,500. The scope weighs about 8 pounds and can be operated with a battery. A 5 gallon container of couplant costs $240.00 but will last a very long time.

Although ultrasonics have been in widespread use for many years, there still remains some doubt about the accuracy of their measurements in some circumstances. Slight pitting such as an "orange peel" surface does not pose a problem. A heavily pitted or highly corroded surface, can reflect a large portion of the input energy which can reduce the effectiveness of the instrument. On such areas, measurements may not be possible with digital instruments. However, advances in probe technology, now under development, such as electromagnetic probes, may enable readings to be taken without the removal of scale or erosion deposits.

Ultrasonic testing is widely used in marine inspections and is well developed. No further research by the Coast Guard is necessary.

5.5 Multiple Probe Ultrasonic devices

Developments in ultrasonic measurement systems are currently underway that may have some future application to marine inspection. In the aircraft industry, McDonnell Aircraft Company has developed the Mobile Automated Ultrasonic Scanner II (MAUS II). This instrument is shown in Figure 12. The MAUS II uses a 'C'-Scan ultrasonic technique to provide a thickness map for the

Figure 12 MAUS II

entire surface inspected. In the 'C'-Scan approach, multiple sensors are used. The signals received must be computer processed to determine the thickness of plating under each sensor plus the thickness of plating in the span between sensors. By moving the probes at a uniform rate, a band of the plate can be thoroughly inspected. This inspection system significantly reduces the amount of time required to manually perform inspections, interpret the information, and archive the results. Inspection options available include ultrasonic pulse-echo, ultrasonic resonance and eddy current methods. The system can inspect large surfaces at rates of up to 100 square feet/hour.

The complete system consists of a computer work station which utilizes windows and menus, a computer mouse and the alphanumeric keyboard. The workstation also has a high resolution display, high or low speed modems, disk drive, optical disk, or magnetic tape storage capability, and a plotter for hard-copies. The system comes with a system manual and a five day training course on operations and maintenance. Cost of a typical system is about $150,000. Operating costs relate mostly to the cost to setup and move the equipment between inspection sites on the vessel.

This system incorporates several good NDT techniques and is commendable, but further design and testing would be necessary to make it adaptable to a tanker environment. This system was designed for operation in a clean production environment. The MAUS II scanner is hand held so the inspector is still faced with accessibility problems. In addition, the system's portability is only in it's distance from the workstation. For tanker use, long cabling would be needed if the workstation was located on the deck. Still another problem is in surface area preparation and couplant application. The system is currently designed for smooth, corrosion free surfaces.

Numerous other multi-probe ultrasonic test setups have been used for years by industry but nearly all are application specific. Many are also tied to an inspection bench and are not portable. Examples of these are ultrasonic arrays for inspecting artillery shells and for continuous inspection of railroad tracks. All of these multi-probe testers rely on inspecting parts of exactly the same size and configuration. This consistency is not present in a ship's structure.

While multi-probe ultrasonic devices could be used for shipboard inpsections, they do not offer significant added value to justify the development costs involved.

5.6 Magnetic Particle Inspection

Magnetic particle testing (MT) has been practiced worldwide for over 50 years and is recognized as one of the most extensively used and cost-effective nondestructive testing methods. Today, such industries as aerospace, automotive, foundries, shipbuilding, general metalworking, ordnance, petroleum, and construction routinely use MT. When properly used, it can reliably identify surface and near-surface discontinuities in ferromagnetic parts. A full range of state-of-the-art equipment and magnetic particle materials are available to handle the full spectrum of industrial applications.

MT is easily carried out with well proven equipment and can be used underwater. The principal is simple: If a magnetic flux parallel to the surface of a steel component encounters a crack, the flux becomes distorted. This flux leakage attracts ferromagnetic particles which are applied to the surface of the steel in a liquid suspension. (In some cases fluorescent particles are used to enhance perception.) The resulting concentration of particles at the crack delineates the crack. When performed by trained personnel the method is very effective at finding cracks. The technique is carried out using an alternating current, AC, yoke, Figure 13, or a permanent magnet kit which costs about $450.00 and weighs about 4 pounds. The ferrous powder costs $8.00 per pound which is enough for 50 feet of weld. An experienced technician can inspect 2 feet of weld in about 15 minutes.

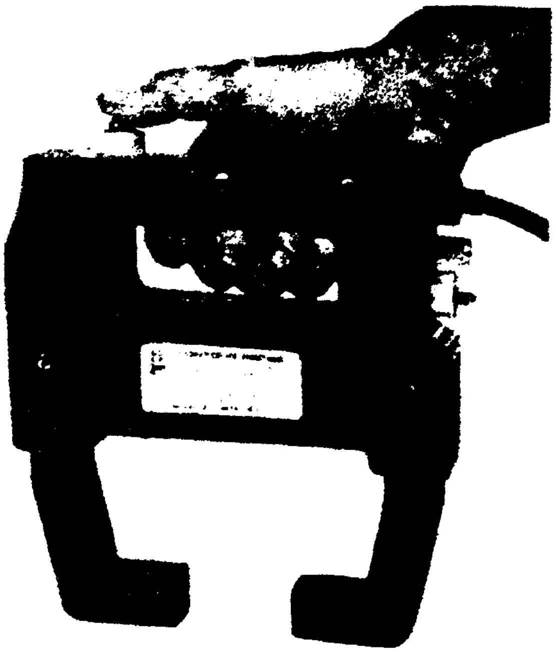


Figure 13 Magnetic Yoke

Some drawbacks for ship inspection applications are the small surface area inspected, long setup time, and training requirements if performed by marine inspectors. Users of this technique with a restricted understanding of its theoretical background may misuse it or not use it to the full potential. Results are greatly affected by the flux density obtained. Special shims with known defects are now used as a quality control measure. These shims have been used in Japan for over 25 years but were only recently adopted in the United States. Shims are especially important if the part being examined is of complex shape causing uncertainty in the flux distribution. If the crack is parallel to the lines of flux, the crack may not show up well in this test. The surface must be thoroughly cleaned and the smoothness of the surface will affect the accuracy of the test.

If the most accurate method, an AC yoke, is used, then a 110 Vac power source is necessary and spaces must be certified safe for hot work. A permanent magnet can be used with less sparking danger to provide magnetic flux but its sensitivity is less than that of the AC yoke and it may lose magnetism over time. For marine inspection application the MT technique is usually limited to inspecting weld repairs and is done by certified technicians.

The Coast Guard should continue to rely on use of outside certified technicians when MT inspections are required.

5.7 Eddy Current Testing

The use of eddy current techniques to detect both surface-breaking and buried defects in thin walled tubes are now well-established. It is now considered a method of crack detection

secondary only to magnetic particle inspection for tube inspection. The method involves a current carrying coil which induces a mutual inductance when it is placed next to a test surface. Any flaws on the surface of the test area affect the eddy currents induced in the test specimen which in turn produce electrical changes in the coil. By measuring these electrical changes it is possible to detect the presence of flaws. Eddy current equipment is suitable for crack detection, crack sizing and determining coating thickness.

The equipment is portable and involves a hand unit (containing the operating coil and signal amplifier) and equipment for processing the signal and displaying the output on a vector display CRT. The equipment costs between $15,000 and $30,000. It must be calibrated by examining a test-piece containing notches of known dimensions. The operator must be trained and skilled to adjust sensitivity and vector rotation, and interpret and record the CRT display.

Eddy current methods are sometimes used for plate inspections but ultrasonics is preferred for such applications. This technique is not used to inspect welds because the irregular weld surface produces a larger signal than any cracks. The principal problems in applying eddy current testing to vessel inspections are rough material surfaces and the high operator skill level required. A rough surface can cause inadvertent lift-off of the probe from the surface being scanned which can affect the signals. To date, marine application have been limited to inspection of heat exchangers. No further development of this technique by the Coast Guard appears beneficial.

5.8 Alternating Current Potential Drop (ACPD) and Alternating Current Field Measurement (ACFM)

This method is used to size fatigue cracks in steel structures. When an alternating current (AC) flows in a conductor the associated varying magnetic field confines the current to a layer near the surface. This phenomenon, known as skin effect, forms the basis of the ACPD method of measuring crack depth. A current of constant strength is passed through the component and two electrodes at a fixed spacing. A potential is measured adjacent to the crack (in unflawed metal) and across the crack. By assuming that current flow is confined to the surfaces of the component and the crack, and that the potential drop is proportional to the current path length, crack depth can be calculated from the distance between electrodes.

Commercial instrumentation falls into two categories:

- ACPD instruments based on low amplitude, high frequency (1-4A 5-10 kHz) current source. In use, separate measurements are made and crack depth is computed manually.

- Magnetic Particle Inspection current sources delivering 100-300A at a frequency of 60 Hz. Potentials are measured to each side of the crack, averaged, and a microprocessor calculates the crack depth and displays it directly.

The ACPD method is normally used in conjunction with magnetic particle testing (MT). The MT technique is used to make the crack visible and the ACPD technique is used to size it. Although the technique has existed for many years its use is not widespread mostly because the instruments give unstable readings and the technique suffers from the effects of poor probe contact. In a ship's tank environment the surface preparation necessary to obtain reliable results could prove to be very time consuming.

A new method developed from the ACPD technique is known as alternating current field measurement (ACFM). Equipment for this technique is shown in Figure 14. This method enables crack detection as well as sizing, using probes that do not contact the surface. The standard ACFM probes contain both the field induction unit and the magnetic field sensors in one integral probe head. No electrical connection is required to the structure being inspected, so a minimum of cleaning is necessary. The probes are designed primarily to run along a weld toe, where most fatigue cracks are found. A standard inspection involves two probe passes, one along each weld toe. A standard AFCM probe can inspect an area about 10mm either side of the probe center. The speed of the scan is about 10-20mm/sec. An inspection consists first of a series of initial probe scans for detection. Having found a defect indication, a crack size estimate can then be performed to determine the length and depth. Subspec Oceanics, LTD has a system specifically developed to perform underwater inspection of welds for the offshore industry. The company claims its ACFM Microgage provides reliable and repeatable inspection results, and requires minimal operator interpretation. This system is sold in the United Kingdom. Cost for an above water ACFM inspection system is about $12,600 ($1.57/£).

Figure 14 ACFM Equipment

This equipment is worth considering if crack depth information is needed. To date this has not been considered essential for marine inspections.

5.9 Acoustic Emissions

Basically, acoustic emission testing is nothing more than listening for the sounds of material failure. As such it is probably the second oldest NDT technique. Potters as long ago as 6500 BC probably listened for sounds of cracking of pots as they cooled as a sign of failure. Tin Cry has been documented as a characteristic sound emitted by tin as it is stressed as far back as the eighth century.

The acoustic emission (AE) technique uses the release of high frequency energy from a structural failure when the structure is stressed beyond its normal operating limits. A propagating crack or a loose structural member emits a high frequency sound which can be

picked up by a series of strategically placed sensors. Measuring the sound's arrival time at each sensor allows the inspector to calculate the source location. The more sensors used, the more accurately the system will locate the source. Once the system has determined there is a failure another NDT method can be used to pinpoint and size the flaw.

This technique is frequently used to inspect high pressure cylinders and nuclear reactor pressure vessels. Proof pressure loads are used to stress the containers above their normal operating limits. The interior surface is generally smooth and any indication of cracking is very serious. Attempts are being made to expand this method to more complex structures. There are many problems to be overcome before the method could be used reliably on a structure as complex as a ship's hull. Some research is currently underway on bridge and railroad car inspection, which are similarly complex structures. Before a system could be deployed on a ship, much experimentation is needed. Ships could contain hundreds of flaws from new construction which have little impact on structural safety. The sound emitted from these small flaws could mask a major flaw. The effects on signal attenuation from surface wax, crude residue, corrosion, paint and liquids in the tank also need to be studied. Other experiments needed involve placement of sensors for maximum and optimum coverage of the ship. Background noises on an operating ship must also be filtered out.

Under high stress any cracks present will experience additional failure at their ends. These failures emit sound which travels to the surface of the material. From the surface, some sound travels by air and some along the material surface to the location of the sensor. In a complex structure there are many possible sound paths. This makes locating the source of the sound very difficult. With multiple sources emitting sound at the same time, the magnitude of the problem increases. However, techniques to solve this problem are under investigation and a solution may be found.

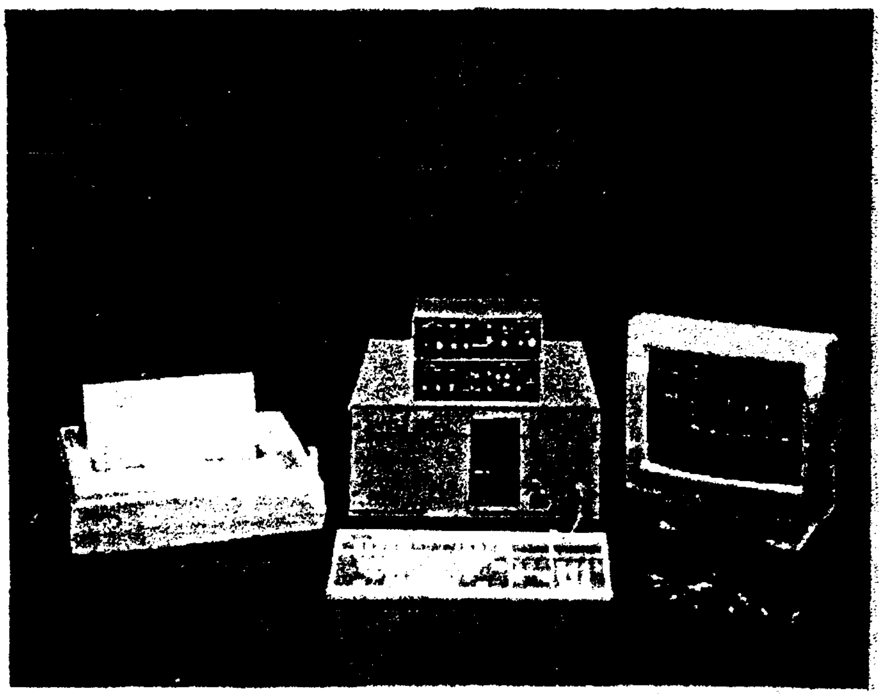


Figure 15 Acoustic Emissions System for Experiments

Because of the need to induce large stresses in the ship, drydock inspections using AE are not practical. The most likely scenario for AE is to permanently install sensors throughout the ship structure to record sounds at sea. The stresses would either occur naturally from flexing in waves or be induced by transferring ballast while the ship is on

a ballast run. Trained technicians could monitor the equipment and make a report upon arrival, or the system could record data to be analyzed by inspectors at a later time.

A small system that can be used for experiments sells for about $20,000. This system is shown in Figure 15. The system includes 4 sensors and all the necessary electronics and software to conduct tests. The equipment can also be rented. Equipment costs are $2,000 per channel (one channel per sensor) plus $20,000 for the electronics and software. Initial set-up time is lengthy due to the extensive cabling involved, but it only has to be done once if the system is permanently installed. Acoustic emission is one of the few NDT method that has the potential of inspecting very large areas in a short amount of time. If experiments prove successful this could be a very useful and safe technique for ship inspections and monitoring. However, a great deal of research must be done before this technique can be used in the field. The Coast Guard should consider sponsoring research on shipboard application of this technique.

5.10 Radiography

The principle of radiography is simple and widely understood. Material to be radiographed is placed between a source of radiation and a photosensitive film. As the intensity of the radiation attenuates according to the thickness and radiographic density of the material through which it travels, subtle variations in material thickness, density or quality result in corresponding variations of radiation strength recorded on the film. The radiation sources normally used are X-ray generators or radioactive isotopes such as Iridium. For material thickness of 1 inch or less an X-ray generator can be used. Figure 16 shows the equipment needed for an X-Ray test. For greater thicknesses a radioactive isotope is used.

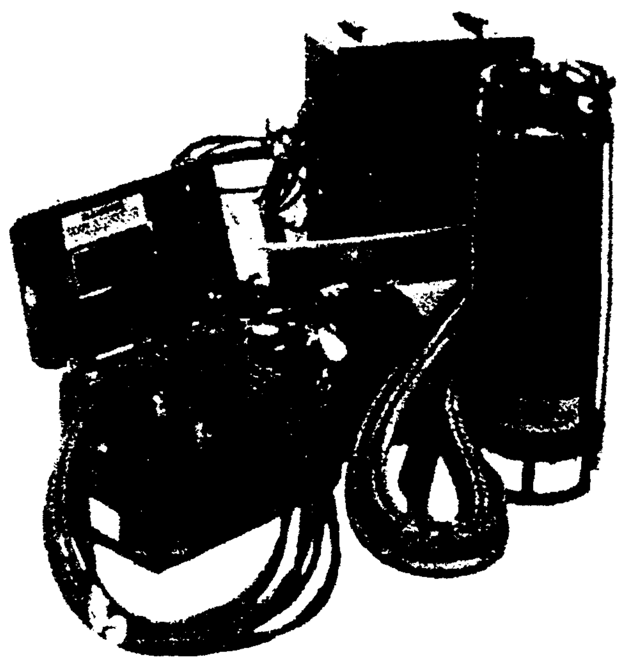


Figure 16 X-Ray Test Equipment

Radiography has been used for years in ship construction and repair to check critical welds. Portable, light-weight equipment is readily available for ship inspections. A 110 VAC or 220 VAC 250 KV unit costs between $10,000 and $20,000, and a 350 KV unit costs from $60,000 to $70,000. Other equipment needed are the film and the film

processing lab. The time involved to perform an inspection is difficult to estimate because there are many variables involved. A very general estimate would be 2 exposures per hour using 17 inch film. It would cost about $1,000 per day for an NDT contractor to keep 2 men on site with all necessary equipment.

For marine inspection radiography is used to inspect through welds, such as plate to plate butt welds, but not for fillet welds. The image is much more difficult to interpret with fillet welds and setup is also more involved. Access to both sides of the structure is required.

Radiography is also sensitive to orientation of planar defects. To detect cracks and laminations the plane of the defect must be aligned with the direction of the radiation source. Standards of known density are usually placed in the shot along with the section being inspected for use in quality control. Since the procedure does not yield real-time data, it is likely that many defects will go undetected unless a very large number of photos are taken. Some of the drawbacks for marine inspection are that qualified personnel are needed, the area must be controlled while the work is performed, the film lab must be brought on site and more training is required because of the need to handle and transport radioactive materials. The spaces inspected must be certified safe for hot work.

The Coast Guard should continue to use certified contractor personnel when radiographic inspection of welds is needed.

5.11 Weld Surface Microstructure

Due to an occurrence of premature hull fractures in relatively new super tankers, research was conducted at MIT on a form of NDT which could detect fatigue cracks when they are still at the microscopic level. By studying how fractures originated steps can be taken during design and construction phases to minimize the metallurgical weak points which can result in these failures. The procedure that would be conducted in a shipyard is simple. It involves manually taking replicas (impressions of the surface to be tested) using replicating tape at areas where the highest stresses might occur. After the impression is made it is stored in a glass microscope slide to be brought back to a laboratory for evaluation. The replicas are a permanent record so storage of the slides is needed. It takes about 5 to 10 minutes to make each replica and the material costs about $0.20 each. Ideally, a baseline set of replicas should be taken at construction and the locations marked so subsequent replicas could be taken at the same locations. This procedure also lends itself quite well to monitoring repair welds.

Testing has shown that the surface microstructure of a weld does change due to fatigue. This procedure warrants further development. All oxides, slag, paint, coatings, etc., must be removed from the weld so only the micro cracks at the weld are examined. Better ways of cleaning are needed. Sand blasting and grinding mask or change the micro cracks. Tracking methods for where the replicas where taken and their orientation is another area needing development. A third area needing study is which welds to replicate. The procedure is rather

labor intensive so making hundreds of replicas may not be feasible. A database of high stress areas or problem areas needs to be developed for different classes of vessels.

This technique is useful for research but is too time consuming to be a practical method for routine inspection.

5.12 Thermography

Infrared thermography techniques have been widely used on land to produce maps of infrared emissions from a target area. The basic principle is to use infrared thermography cameras to locate temperature differences which may indicate an area where corrosion or cracking has taken place. To date there has not been any application to tanker hull inspections, however, the technique has the potential to inspect large surface areas in short amounts of time.

Monroe Infrared Technology in Kennebunk, ME has extensive experience in this technique, and has applied it to electrical, mechanical, building maintenance and boiler studies, to name a few. The company suggested a method of somehow heating up one side of the hull (outside or inside) and scanning the other side for corrosion or cracks. Heating the hull would be a big expense if practical at all. One possibility is to conduct the inspection in the evening after the hull has been heated by the sun all day. Once the hull is heated up, the infrared camera could scan a large area in a short period of time. The equipment used is very portable and the inspection could be recorded on videotape along with voice descriptions. A typical system includes a camera, lens, video cassette recorder and accessories, and two carrying cases. The system costs about $20,700. Operational training is provided by the factory and through manuals. One day is required for training on hardware operation and two days are required for software training.

Although the technique has been very successfully applied to many industries, thermography needs further study for tanker inspection applications. How best to apply heat to the hull efficiently and evenly is the major problem. Determining what kind of flaws the scanner can detect on the structural members is another. This technique may only be useful to check the hull for corrosion, cracks or coating thickness.

Since this technique offers some promise for inspecting large areas rapidly, it may be beneficial to conduct further research on the use of this technique for ship inspection.

5.13 Shearography

Shearography is a laser-based optical inspection technique which measures surface motions (strain) on the surface of the piece being inspected. The surface must be viewed at two different stress levels. The information from both stress levels is processed in a computer and interference patterns are projected on a viewing screen. Strain components due to internal stresses related to sub-surface flaws and surface flaws is readily shown.

Shearography may be used on composite laminates, thermoplastics and foam core materials, metallic or composite honeycomb and bonded structures to detect subsurface defects such as unbonds, voids, delaminations, and impact damage. It has some potential for use with solid metal structures to detect subsurface and surface defects.

The disadvantages of shearography limit its usefulness for shipboard inspections. The primary disadvantage is the need to create two stress levels for each location viewed. While the difference between these stress levels can be small, changing the load on the hull for a small inspection area is not very practical. Systems are available that are reasonably portable which can inspect about a 2' x 3' area for each setup. Such a system costs about $50,000. This is a relatively small inspection area considering the fact that two loading conditions must be used for each area inspected. Shearography is not a practical method for shipboard inspections except for small areas suspected of having subsurface defects. Such occurrences are rare.

5.14 Vibration Monitoring

Vibration monitoring and vibration fingerprinting have been used on simple structures to indicate changes in characteristics. A change in the vibration characteristics usually indicates that some structural failure has occurred. These techniques are best described as early warning techniques to indicate that a detailed investigation is needed to determine the cause of the change in vibrations. Vibration monitoring is simply recording vibrations of the structure at different times and comparing the vibrations taken. Any changes may indicate a structural problem. There are significant background vibrations present on a ship which limit the usefulness of vibration monitoring. Most of the changes in vibrations are due to this background noise. For example, a change in engine speed causes new frequencies of vibrations. To be effective as many outside variables as possible must be held constant during each reading. This limits the effectiveness of this technique. ARCO has a small project investigating the use of vibration monitoring as an inspection technique.

Vibration fingerprinting is less susceptible to background noise because it is a short term measurement. In fingerprinting, a pickup is mounted to the structure and the structure is vibrated, usually be striking it at a known point with a hammer containing a force sensor. The resulting vibration pattern is recorded and corrected for the force of the hammer blow. At a later date, the process can be repeated and compared to the old data on file. If there are significant differences, the structure may have failed. A large number of vibration fingerprints for a typical tank structure would be required to effectively cover the structure. Use of vibration fingerprinting on ships is presently under study by Dr. Mazurik of the U.S. Coast Guard Academy and investigators at the University of California, Berkeley. These studies may lead to breakthroughs making it more useful in the future. For now it is not a tool that can be used for shipboard inspections. The Coast Guard should monitor the results of on-going research to determine if this method has future application.

5.15 NDT Summary

Table 8 summarizes the advantages and disadvantages of vision enhancement methods.

Table 8 Vision Enhancement Methods

Method	Application	Advantages	Disadvantages
Illumination	All visual Inspection Techniques	Provides better visibility for all inspection techniques	Cost and setup time is greater for higher intensity lighting
Telescopic Devices	Provide magnification of inaccessible areas within ship	Low cost alternative for access to structure that would otherwise need staging for access	100% viewing of tank is not possible. Binoculars add to inspectors load and are extra expense.
Borescopes Endoscopes	Inspection of small enclosed structures	Best viewing technique for looking into small spaces. Well proven with little training required.	High cost for limited application
Remote Video	Remote inspection of tank internals.	Frees inspector of hazards of tank entry. Provides permanent record on tape.	100% viewing of tank is not possible. Vibrations can blur image. Needs electrical source.
Night Vision Equipment	Improves visibility inside tank where lighting is not available.	Allows viewing at low light levels. Equipment light weight and can provide magnification.	Monochrome image. Resolution may not be good enough to detect small defects.
D-Sight	Enhanced view of surface distortions, depressions, protrusions and stress cracks	Able to inspect relatively large areas quickly. Fast setup and relocation.	Developmental for large area inspections. There may not be adequate reflection from surfaces for technique to work.

Table 9 summarizes the advantages and disadvantages of NDT methods, other than visual, which might have application to shipboard structural inspection.

Table 9 Nondestructive Testing Methods

Method	Application	Advantages	Disadvantages
Dye Penetrant (PT)	Detection of surface cracks in welds and plates.	Well proven and widely used. Simple to use, accurate, & fast, if used properly.	Trained operator required. Defect must be accessible. Area must be thoroughly cleaned.
Ultra-sonics Testing (UT)	Spot checks of plate thickness & detection of surface and subsurface cracks or flaws.	Well proven and widely used. Fast, dependable, easy to operate. Immediate results and very portable. Can be used under-water.	Trained operator required. Electrical source may be required. Rough or pitted surfaces can distort readings.
Multiple Probe Ultra-sonics	Detection of surface and subsurface cracks and plate thickness over an area of plating rather than at points on plating.	Well proven for specific inspections. Fast, immediate results, accurate, easy to operate.	Not previously used for marine inspection. Trained operator required. Electrical source required. Only tested on smooth clean surfaces. Limited portability.
Magnetic Particle Inspection (MT)	Detection of surface or near surface defects in steel surfaces and welds.	Well proven and widely used. Simple and quick. Equipment is very portable. Can be used underwater.	Trained operator required. Electrical source may be required. Surface must be thoroughly cleaned. Surface smoothness will affect accuracy.
Eddy Current Testing	Detection of surface and subsurface defects. Used primarily to inspect tubes of heat exchangers	Accurate in the hands of an experienced operator.	Little apparent application for hull inspection work.
AC Potential Drop/AC Field Measurement	Detection & sizing of cracks in welds	Light, rugged, portable. ACFM has no contact probes. Can be used underwater.	Has not been used before for vessel inspection. Trained operator required. Electrical source required.
Acoustic Emissions (AE)	Determination of fatigue cracks. Can be used as early warning or monitoring system.	Could be best large area monitoring method if it can be developed to apply to hull structures.	Although successful on simple structures, it has yet to be tested on complex hull structures.
Radiography	Determination of cracks and defects in welds.	Well proven method used on ships for years.	Slow & expensive. High level of operator training.

Table 9 (Continued) Nondestructive Testing Methods

Method	Application	Advantages	Disadvantages
Weld Surface Microstructure	Early detection of fatigue cracks at the microscopic level.	Provides hard copies of weld surface structure for baseline and reinspections. Taking each sample is quick and inexpensive.	Still experimental. Requires good cleaning. Lots of samples and post inspection analysis is needed.
Thermography	Used to locate areas of heavy corrosion, inclusions and cracking anywhere on structure.	Large area can be viewed quickly.	Requires heating the hull. Untested in hull inspection applications. Not clear how heating requirement can be met for practical application.
Shearography	Used to locate surface and subsurface flaws mostly in composite panels.	Subsurface defects are detectable	Requires changing stress in the structure. Coverage is limited to about 6 sq ft per setup.
Vibration Monitoring and Fingerprinting	Used to detect changes in the structure's vibration patterns which may indicate that a failure has occurred.	Covers a fairly large but ill defined portion of the structure at each sensor location.	Technique not well developed for use on ships. Requires numerous measurements. Background vibrations are a serious problem for monitoring.

6.0 INDUSTRY SURVEY OF ACCESS ENHANCEMENTS

Regardless of the type of NDT used, its usefulness will be greatly enhanced if close up access is provided to the structure being inspected. Most NDT methods require cleaning of the metal to remove oil residue, rust, dirt, and loose paint. This can only be accomplished effectively with close up access.

Ship designers pay little heed to structural access requirements and owners often consider built in access provisions not to be cost effective. Extra ladders and walkways add weight and reduce the carrying capacity of the vessel. Such accesses require maintenance and painting which also adds to the owner's costs. However, if the additional vessel downtime and the cost of installing staging for shipyard repairs is factored in over the life of the vessel, it may prove less costly to install permanent means of access.

The advent of double hull tankers provides a historic opportunity for the Coast Guard to require improved access. Most of the structure on these ships is located in the narrow wing tanks. Requirements for horizontal platforms at vertical spacings of 3 meters or less in the wing tanks would make most of the ship's structure accessible at little extra cost.

Regardless of new requirements for better means of access, there will be hundreds of vessels without these improvements for many years. The sections which follow discuss various options for obtaining access to vessel structure. Some can be used today on any ship and some are recommendations for future designs.

Inspection access is usually not too severe a problem on dry cargo vessels as these have intermediate decks at reasonable vertical spacing. Often, the only access improvement needed is a step ladder to reach the overhead. On tankers and certain bulk carriers the height from the bottom structure to the overhead can be 40-100 feet and sometimes even more. Most of the methods below are discussed with application to tankers as these vessels present the most serious access problems. The access methods can be used on other ship types in most cases.

6.1 Access Provisions on Ships in Service

6.1.1 Installed Ladders and Walkways

Typically, only a very limited portion of a tank (the bottom and some stringer platforms) have installed accesses on a tanker. Some ships have permanent ladders only to the forward or aft stringers, not both. This makes the opposite side of the tank and the transverse bulkhead inaccessible without some form of staging. Access to the overhead of the tank is seldom, if ever, provided.

Robert Holzmann, in reference 7, lists a number of methods for improving tanker access. These are provided below.

"Those methods that do not significantly affect the structural design include;

1. Fitting permanent walkways and ladders at strategic locations within the tank, particularly walkways below the overhead and ladders along the transverse web frames.

2. Attaching permanent clips or lugs on the internal structural members for use of temporary staging, or for attaching ropes or retractable lifelines for use during an inspection.

3. Installation of both forward and aft ladders to access stringers (if not already fitted).

4. Investigation of alternative materials for ladders, such as fiberglass to eliminate corrosion problems and thus eliminate maintenance problems.

5. Additional installation of handholds to provide access to critical structural members. This may avoid the need for costly staging during inspections.

6. Use of lighter coatings in ballast tanks. Lighter coatings provide an easier means to detect cracks which produce rust streaks and discoloration.

7. Provide handholds in the underdeck transverse web frames. When rafting is conducted the tank is ballasted to within one meter of the underdeck transverse web frame. This can leave the inspector several meters away from the underdeck connections. By providing a means to climb to the overhead from the raft, close up inspection is assured.

"Those methods that may significantly affect the structural design include;

1. Installation of extended longitudinals every fourth or fifth longitudinal or at a very minimum in the uppermost region of the tank to act as walkways for the inspector. These walkways should be fitted with handrails or a similar arrangement to which the inspector can clip into with a safety harness. Safety harnesses should become standard operating equipment for the inspector when the inspection is conducted above the tank bottom. . . Extended longitudinals will more than likely impair the tank cleaning process. Additionally, they may also introduce unwanted structural detail when carried through the transverse web frames. With an extended longitudinal in only then uppermost region, these disadvantages would be minimized.

2. Increase spacing of structural members in certain limited space areas to facilitate ease of access. Not all inspectors have small framed bodies.

3. Avoiding blind spots in structural members where visual inspection without the use of mirrors is difficult. This will facilitate repair work involving welding.

4. Providing permanently installed access plates or holes for entering tightly arranged structures.

5. Reconfigure underdeck longitudinals so that they are on the tank top.

6. Tank hatch openings with limited ladder access should be included in each bay between transverse web frames. This would allow the tanks to be ballasted beyond the one meter below underdeck transverse web frames limit and allow for close up inspection of the underdeck longitudinals."

Ladders and catwalks have the disadvantage of using fairly light structural members whose strength is affected by corrosion disproportionately to the heavier members in the ship's structure. Corrosion that could be tolerated on a hull stiffener may make a ladder unsafe to climb. Therefore, painting and maintenance of accesses can be costly or, if ignored, can pose safety problems. An alternative is to build access provisions into the structure. Some have been mentioned by Holzmann above. Vertical structure can be made into ladders by extending one side of the flange of transverse frames with a plate containing hand and foot holes or by making the web of the frames strong enough to accommodate hand and foot holes. Such structure may be heavier than a ladder but the likelihood of weakness due to corrosion is much less and no additional maintenance would be required. This should result in a net cost savings to the owner.

6.1.2 Inspection from the Tank Bottom

Walking the bottom of the ballast or cargo tank area is often the first step in inspecting a tank. All members of the inspection party can participate in the close up visual examination of the structure near the bottom and some form of access to the bottom is always provided. Thus, this part of the survey requires no setup time.

Access to structure above 10 feet from the bottom is highly dependent on installed ladders, walkways, etc. In most cases, access is restricted to a very limited portion of the tank. A limited amount of inspection can be done from the bottom. Major damage such as bowing or buckling of bulkheads can be seen. Serious corrosion or cracking is also sometimes visible. Good lighting and telescopic viewing devices can help in this overview from the tank bottom. However, much of the upper structure will be blocked by other structure and can not be inspected from the bottom. Also, an adequate inspection often requires cleaning the areas looked at and this is not possible without close up access.

6.1.3 Climbing

The least costly means to access upper structure is simply to climb the bulkheads using installed longitudinals as a ladder. This is a very dangerous practice. The longitudinals are usually slippery due to oil or rust coatings and handholds are limited. It is also physically demanding. Both hands are needed to hold on so data recording is nearly impossible.

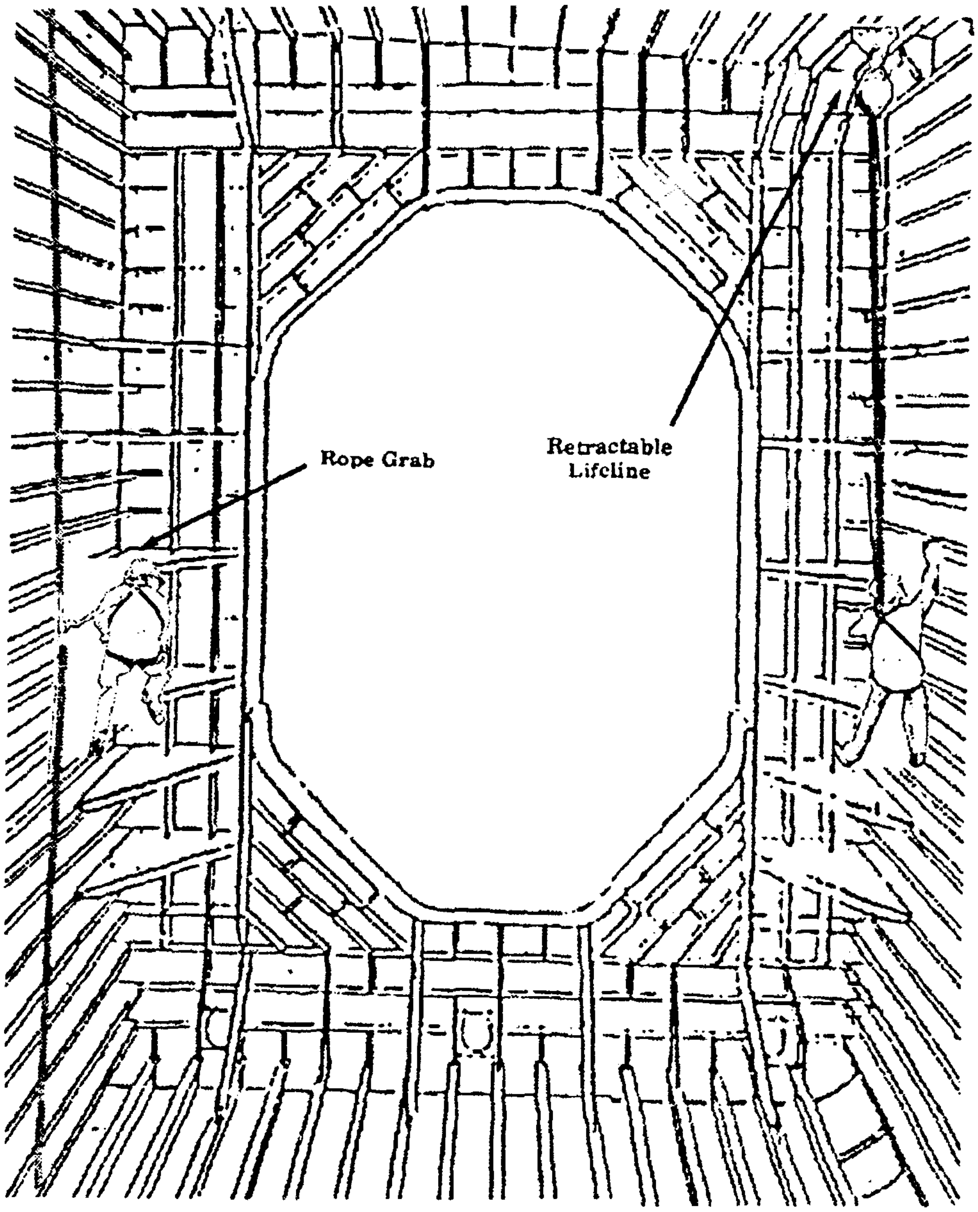


Figure 17 Climbing Safety Devices

Higher climbs can be made if safety lines are used. Types of safety lines include retractable lines attached to the overhead or vertical ropes clipped to an upper side longitudinal with a sliding rope grab attached to the inspector. Both methods require access to the overhead or upper side structure to attach the safety line. Also, all the other disadvantages of climbing are present, making this an undesirable access approach. Figure 17, copied from reference 7, shows two types of Climbing Safety Devices.

Shipping companies generally set a height limit of 3 meters (10 ft) for climbing above a deck surface without safety devices (Holzman). Local Coast Guard OCMIs set policy on climbing, and 10 ft has been used as the standard in most zones. However, in New York, for example, local policy now prohibits any climbing of sideshell longitudinals without safety equipment, and inspectors generally do not carry such equipment, so the policy, in effect, prohibits sideshell climbing entirely.

6.2 Portable Ladders

If ladders are not installed for access, the obvious choice is to place portable ladders in the tank. To a limited extent this is possible. Portable ladders are limited in length by the need to manhandle them from location to location in the tank and by safety concerns associated with climbing any high, unguarded ladder.

A typical system of ladders called "Framewalk" has been developed by Marine Inspection Products of Bath, United Kingdom. It was specifically designed to enable close inspection of upper frames and hold sides in bulk carriers. The system is totally independent of all ship services and facilities, and can be quickly and conveniently used without the need for special skills or training. The system can be easily stored on board the vessel or shipyard. The weight of the system makes it difficult but not impossible to handle with manpower only. A complete kit consists of one extension ladder, one stationary ladder, and two metal cases containing all the necessary hardware and safety equipment. It can be assembled by two operators in about 20 minutes and moved to another nearby location in about 10 minutes. The total system weighs about 420 lbs. The cost of the system is $5,500.

Framewalk was designed for dry bulk carriers with transverse framing, however, the company is in the process of designing a similar system for tankers with longitudinal framing.

6.3 Fixed Staging

Fixed staging, as shown in Figure 18 from reference 7, is preferred by most shipyards, owners, and certainly by inspectors. Fixed staging consists of portable aluminum bars assembled to form vertical supports and horizontal platforms. Planking is laid over the bars at convenient horizontal work levels. A ladder is usually attached to one end of the staging to provide access between levels. This is a well proven method used world wide in all forms of construction and maintenance. Shipyards usually have the components of the staging on hand. However, the labor and costs involved with assembling staging make this method to expensive to use for a whole ship inspection. No special training or physical ability is required of the inspector other than the ability to climb vertical ladders.

Staging can only be used in a repair yard, not at sea. Thus, all survey work must be done after the ship reaches the repair yard. This may delay starting repairs of any damage detected.

6.4 Rafting

Holzman, in reference 7, provides an excellent review of the use of rafting. Figure 19 comes from that source. Most of the material below is also taken from this source.

Rafting is one of the more common methods of surveying tanks while a ship is at sea. This method consists of inspectors surveying the structure in a tank that is partially filled with ballast water. The water level is varied to three or four different levels so that structure from the bottom to the top of the tank can be inspected. The overhead can not be surveyed adequately using this method because the highest water level must be at least 3 feet below the opening in the web frames in order to permit the inspectors to escape should a problem occur. Also, this method can only be used in moderate seas because of the sloshing that occurs in the tanks.

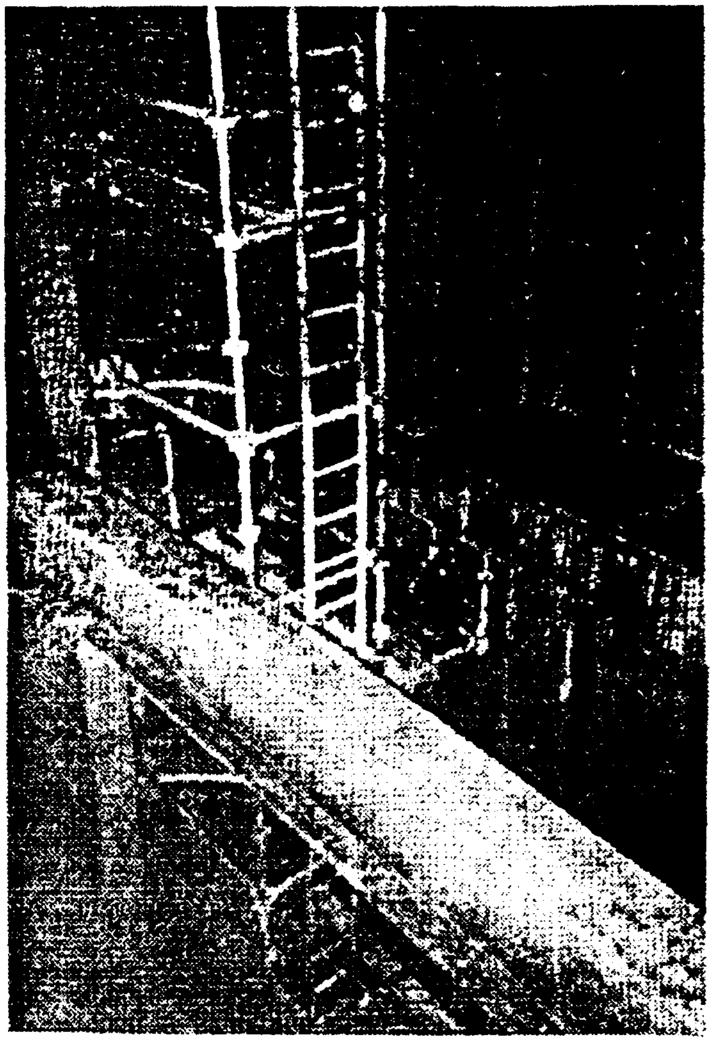


Figure 18 Fixed Staging

Precautions must be exercised with this method. Safety observers should be stationed on deck and in the tank. Inert gas system must be secured and the tanks made safe for entry. Inspectors are hindered due to the need to wear a personal flotation device, PFD.

"An in depth rafting survey can take 15 to 20 days, resulting in considerable out of service costs. Moving ballast takes time and fuel costs associated with transferring the ballast water run anywhere from ten to fifteen thousand dollars per ship inspection." No special inspector training is required other than training in safety precautions associated with rafting.

Rafting is not without its detractors. While many companies believe rafting is the best way to survey a ship prior to entering a shipyard, other companies believe the dangers involved outweigh the benefits and will not use rafts for surveys.

6.5 Work Platforms Suspended from Overhead

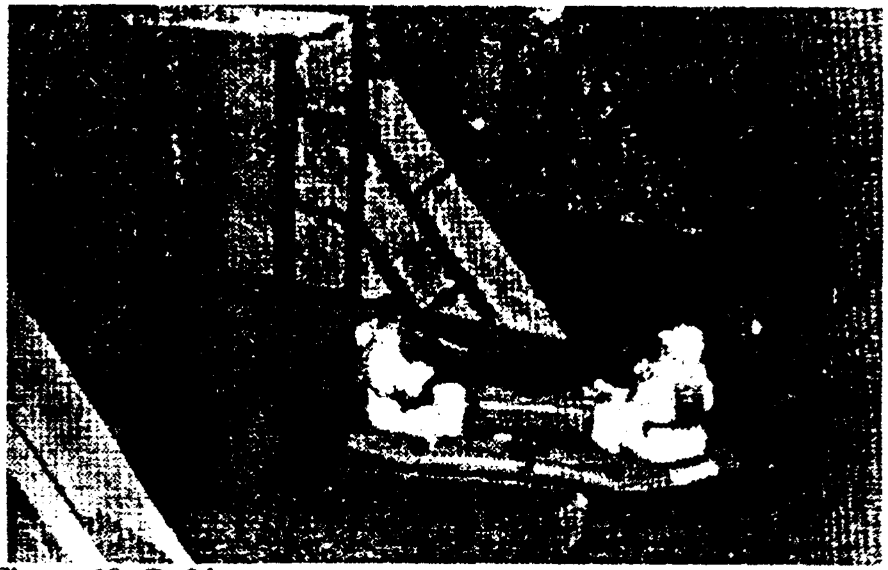


Figure 19 Rafting

This type of staging is similar to that used by window washers on tall buildings. One or two cables are attached above the area being inspected and a work platform or bucket with the inspectors on board is hoisted to the desired height. The hoists are controlled by the people in the bucket. Thus, an inspection at all vertical levels is easily accomplished. Figure 20 shows a typical example. Some products have been designed to be suspended from roller attachments on the deck longitudinals permitting horizontal movement at least between transverse frames.

The main difficulty associated with this type of portable staging is the initial rigging. An I-beam roller or cables must be attached to the overhead longitudinals to initially secure the bucket. The unit itself must then be lowered by crane to the tank bottom deck. Then the cable, air hose and safety harness must be hooked to the overhead. Once this is complete the inspector can move the bucket along the longitudinal using an I-beam roller. If the inspector needs to get around a structural member a transfer chain can be used. By transferring the weight back and forth from the transfer chain to the wire rope, the staging bucket can be "walked" around the structure. Equipment from two companies using this approach are discussed below.

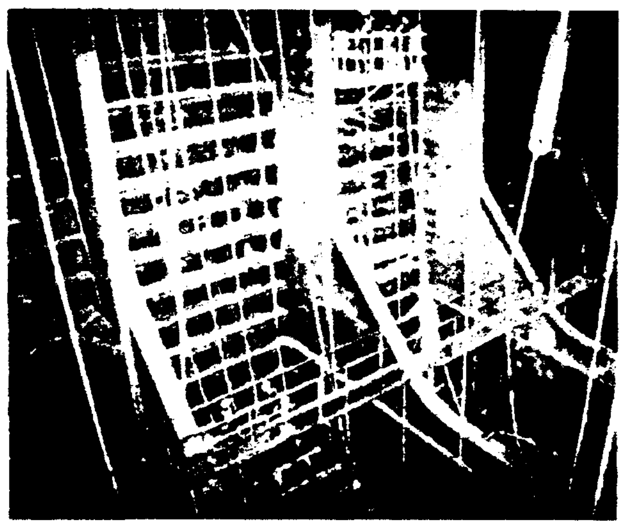


Figure 20 Suspended Staging in Tank

Spider Staging

Spider Staging Corporation manufactures several portable staging devices for marine inspection applications. They can be easily assembled and can fit through openings as small as 18 inches in diameter.

Different units can hold from one to four people, they can be operated with air or electric power, and they are fairly light in weight (from 180 to 200 pounds).

The ST-26 mini-spider (see Figure 21) takes one person about 10 minutes to assemble, and the transfer operation described above takes about 15 minutes to complete. Lowering the unit by crane and securing the cable to the overhead could take up to one hour. Setup times will decrease as an inspector becomes more familiar with the equipment. To inspect an entire tank, the unit will have to be re-rigged to get around large web framing. This involves raising and lowering the unit through different openings and repeating the initial rigging process. Inspecting an entire ship would be very time consuming. The cost of this system is about $6,800 which includes all hardware and safety equipment.

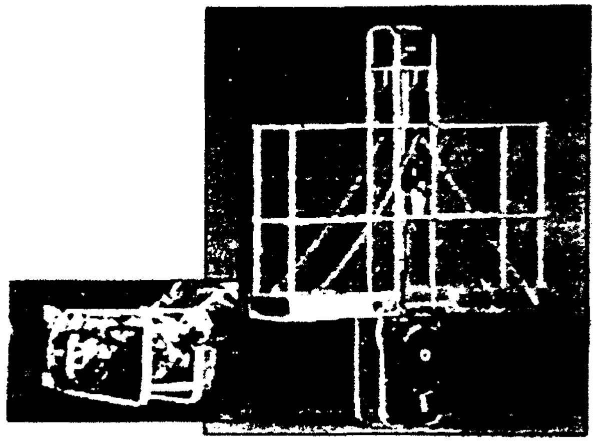


Figure 21 ST-26 Mini-Spider

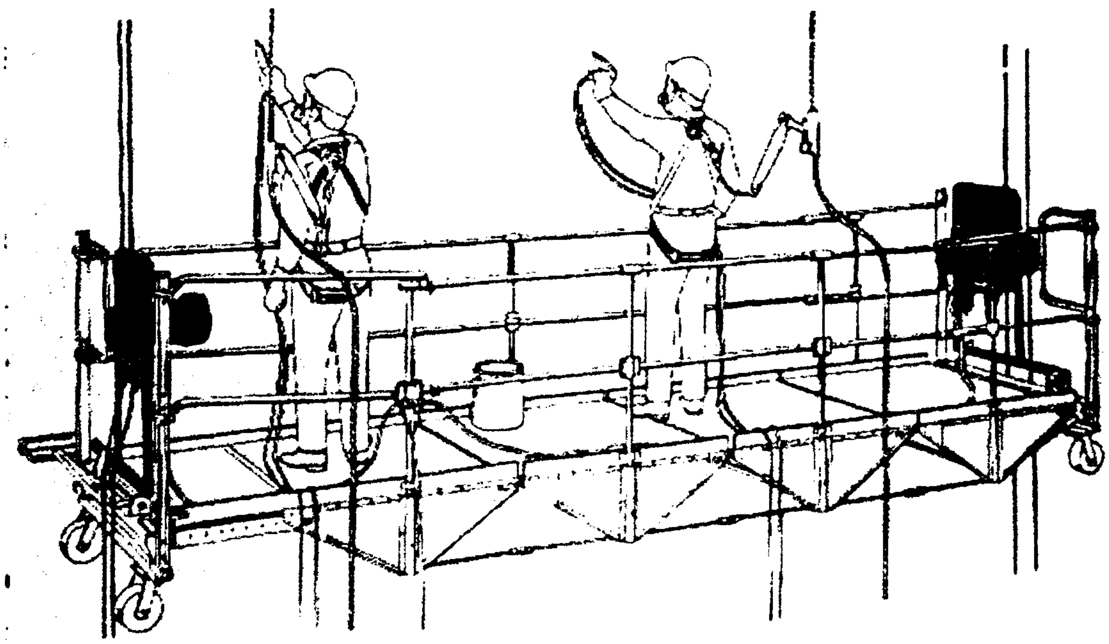


Figure 22 SC-30 Spider Climber

Another unit, the SC-30 Spider climber traction hoist, could also be used. (See Figure 22) This system is similar to a window washer device used on tall buildings. The system

comprises two (2) SC-30s and as many truss sections as desired. Platforms can be from 4' to 36' across. The system is a modular design and assembly is simple using cable socket attachments. Here again, initial rigging is the main difficulty. The original setup time could be up to an hour, but much larger areas could be inspected without moving it. The cost for a typical system is about $13,000. Training and customer support are included with the purchase. Spider Corporation will also provide a free demonstration of their equipment at a customers request. Systems can also be rented or purchased in used condition.

Stageaway

A similar system of portable staging is provided by Stageaway Vessel Support Services of Portland, OR. They are often used for ship inspections on the West Coast. The inspection techniques can be performed while the vessel is underway in moderate seas, at anchor, or in dry dock. The staging system allows safe access to any area of a tank.

Stageaway has trained personnel who can fly to any location in the world, erect the staging, and begin work a few hours after arrival. A setup team usually consists of five people. The company claims to be able to inspect an entire VLCC in four days in port. At sea, they can inspect one tank or hold per day. The cost of a typical inspection is about $4,000 to $5,000 per tank on a VLCC or from $80,000 to $100,000 for an entire vessel depending on shipping costs involved. These prices include a detailed inspection report by a marine surveyor. Staging prices alone were not available. Stageaway has conducted a very detailed demonstration of their system to the Coast Guard in Washington, DC in July, 1992. Figure 20 shows a Stageaway system.

The Coast Guard should consider methods for making it easier to attach portable staging to the overhead structure. This is a very good type of staging limited by the difficulty in attaching cables overhead.

6.6 Articulated Work Buckets

Articulated arms with personnel buckets are used in many different inspection jobs on shore. Usually these are truck mounted. The buckets used by electric linemen to inspect power lines on poles are an example. Another example is the "Snooper" used to inspect underneath highway bridges. Bridges present a similar access problem to the overhead inspection in a tank since the bridge may be hundreds of feet above water.

A Snooper is a truck with a platform or bucket for up to 4 persons attached to a mechanical arm. The truck is first stabilized, and then the bucket is lowered over the side and under the bridge. Once over the side the bucket has good maneuverability. The bucket is controlled by the operator or inspector using a control panel in the bucket. The snooper can cover about 25 feet horizontally. Whenever the truck has to be moved the bucket must be brought back up and the personnel removed for safety reasons.

A similar system for ships was developed for Shell International Marine, Ltd. of London by Sigval Bergesen. This system is known as the Portable Work Platform or "Ziggy". Figure 23 which comes from reference 7 shows this system. It is pneumatically operated and capable of fitting through a tank opening. It is designed to carry one person. The vertical reach is 82 feet and the horizontal reach is about 28 feet. The equipment is segmented into 190 lb sections which could be manhandled by 2-4 people with difficulty. Normally, shipyard crane support is required to position it.

The major disadvantage of these systems is the setup time required. Moving from opening to opening could take 4 or 5 hours. An entire ship inspection would be very time consuming. Their best application would be for critical inspections of overhead areas.

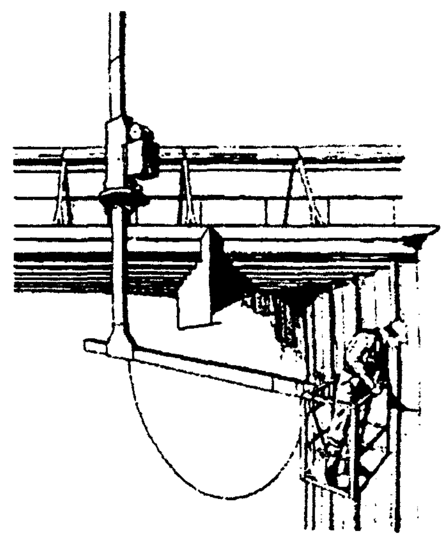


Figure 23 Portable Work Platform

6.7 Magnetic Crawlers

Another access enhancing system which is used in the steel storage tank industry is the magnetic crawler inspection system such as the one manufactured by NDT International, Inc.. This system uses ultrasonic thickness measurement techniques to inspect steel storage tanks, piping and other steel structures not easily accessible to the inspector. It is a completely portable, battery powered system. The crawler is powered by two 12 VDC motors which allow the operator to "drive" the magnetic wheels on the sides or tops of tanks. One motor powers the right side and one powers the left side. Speed range is 1 to 15 feet/minute. A 100 foot cable assembly carries the transducer signals, a flexible plastic tube for water (couplant) and a shielded power cable for the motors. Various other cable lengths can be supplied. Other equipment needed to complete the system are an oscilloscope, strip chart recorder and the Power/Control unit. (See Figure 24) The total cost of the system is about $21,500. A significant amount of operator training is required both for crawler driving and ultrasonic signal interpretation. The system could be used to carry a small video camera for close up video inspection instead of the ultrasonic sensor.

The system works well on smooth surface areas such as hull plating. Inside a tanker, the crawler could run between the longitudinals, however, moving the crawler to the different levels could prove to be time consuming. Access to the upper areas is still a problem. In addition the operator must be able to see the crawler to drive it to the desired location. The system also applies ultrasonic techniques so the previously mentioned problems with rough, dirty surfaces still remain. The manufacturer recommends that the crawler always be tethered from above since it may slip or loose contact with the surface when passing over rust or a heavily

painted area. Stronger magnets can be installed for the wheels. The main drawback of the device is the level of surface cleanliness required to ensure adhesion to the bulkheads and to achieve a good acoustic coupling for the ultrasonic probe. This device is likely to have limited application for tanker inspections.

6.8 Remotely Operated Vehicles (ROVs)

ROVs could be used to inspect ballasted tanks. Most ROVs in use today are tethered vehicles controlled by a pilot at the surface or, in this case, outside the tank. The vehicles carry the equipment necessary for their propulsion plus lights, cameras, navigation aids, an ultrasonic measurement device, and any manipulators needed for surface preparation. The biggest advantage of the ROV is that it keeps the inspector out of the tank and away from hazards involved with tank entry. Figure 25 shows a typical ROV.

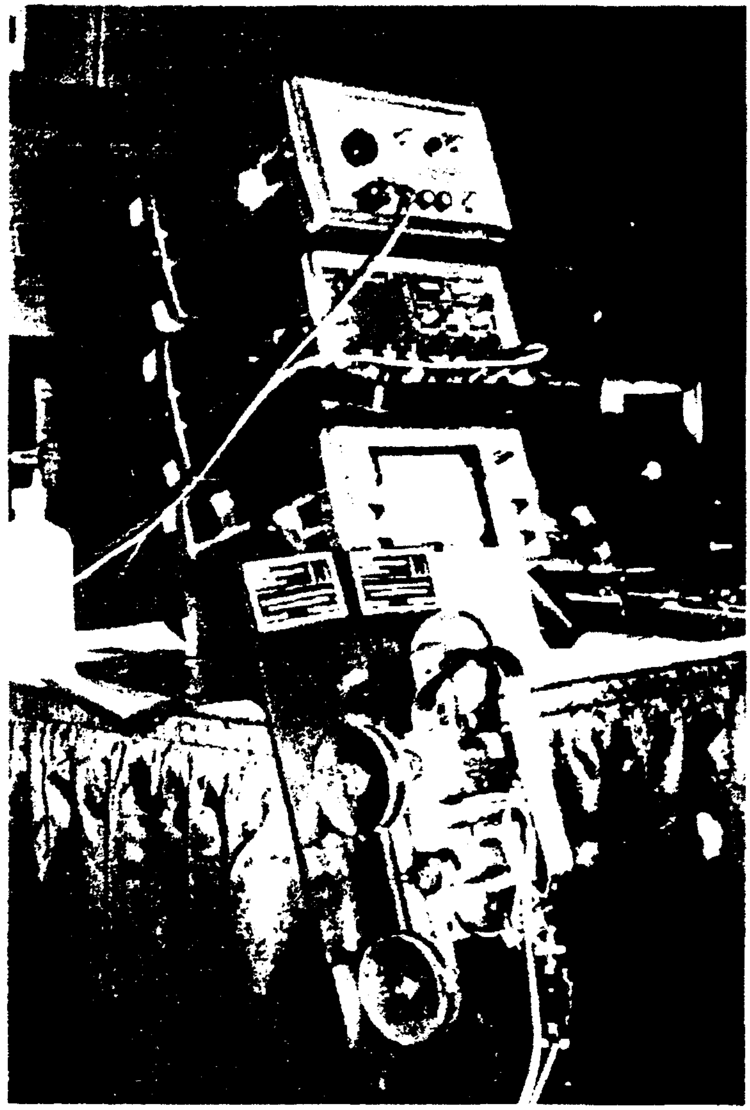


Figure 24 Magnetic Crawler

The use of ROVs for tanker inspection is still in the developmental stage. In 1984, Mobil Shipping sponsored a research program for such a system, but the program was terminated for several reasons. Among them were cost, lack of a reliable tracking system and the skill level required of the tanker crew. ROV technology continues to improve. There are more than 500 types of ROVs commercially available today and also a wide variety of prices and applications. ROVs range from low cost recreational viewing systems to industrial work platforms. Small ROVs can be purchased for as little as $10,000 and some large deep submergence systems can cost several hundred thousand dollars. This report focuses on two manufacturers recommended by the Underwater Robotics Department of the University of New Hampshire which provide equipment typical to that available from other manufacturers. In addition, the report focuses on a typical navigation/tracking system which can be adapted to most

ROVs. Two typical ROVs that are suitable for tanker inspections are the Phantom 300 from Deep Ocean Engineering and the Mini Rover MkII from Benthos, Inc.. The Phantom 300 comes standard with a color CCD camera with manual tilt, a navigation and control console, 2 lights and a 400' umbilical cable. Options include a still camera, a high payload option, a lateral thruster, and manipulators or articulators. This system with a spares kit and some options desired for inspections costs from $25,000 to $35,000. The Benthos Mini Rover MkII system includes a Pan/Tilt, low-light level, high resolution, color TV camera, a lateral thruster, a power console with video graphics, a ruggedized hand controller and a 500' umbilical cable. Options include a two function articulator, 35mm photo camera, navigational tracking system and ultra thrusters. This system can be purchased for $49,000 with options adding another $5,000 to $10,000.

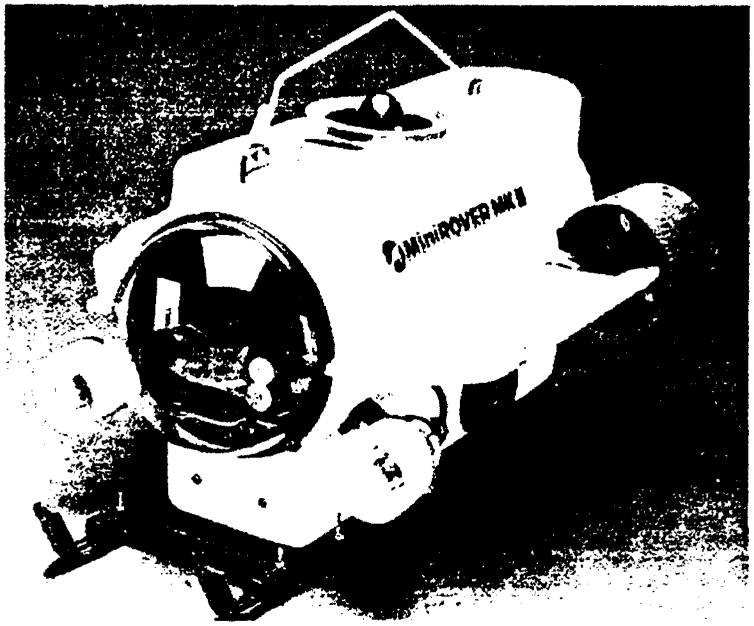


Figure 25 Typical ROV

Either of these systems alone is not adequate to perform tanker inspections. The navigation systems provided are not sophisticated enough to maneuver through the complex structures of a tanker. Marquest Group, Inc. has done extensive work in the area of accurate navigation and tracking for ROVs. They have developed the Sonic High Accuracy Ranging and Positioning System (SHARPS), the Exact Acoustic Tracking system (EXACT), and the ROV Dynamic Positioning system (ROV DP). The SHARPS is a proven system and has been used in various underwater applications. It used three or more cabled transceivers to form an acoustic grid from which a transceiver carried by the ROV can be tracked. All positioning information generated by SHARPS can be graphically displayed to the ROV operator in real time 2-D color and can be stored for later viewing. The SHARPS tracking system costs $38,000.

The EXACT system is specifically designed for precise, short-range surveying and ROV tracking in deep water. It is basically a wireless version of the SHARPS. The system was primarily developed for the offshore industry where cable lengths make the SHARPS impractical. This system has been successfully tested in the U.K. on the Mobil Research Vessel.

Both of the above systems can be used in conjunction with the ROV DP to gain automatic feedback (closed loop) control. To date the nature of ROV operations relied on the hand-eye

coordination of the operator. The ROV DP expands the concept of automatic control to include true computer guided positioning. The company says that from the ship's blueprints an inspection pattern can be programmed into the ROV control system and it will follow the prescribed path. The ROV DP system costs another $35,000.

To date these systems have been used to inspect above ground water tanks, nuclear pressure vessels, offshore oil/gas fields, and for over the side acoustic noise surveys on submarines at the David Taylor Research Center. The systems have achieved much success and the company feels that they can be used to inspect ship tanks.

Although significant advances continue to be made in control electronics, ultrasonics, processing software and ROV miniaturization, there still are limitations for tanker applications. First, the umbilical may become entangled in the complex structure of the tanks. In order to reduce this problem the inspection could be conducted between web frames. This would require moving the ROV several times and thereby increase the inspection time. The second limitation is the amount of time necessary to conduct an entire inspection. Marquest has said that it could take up to two days to thoroughly inspect each tank. Next, there is the tendency of the inspection team to become fatigued and/or disoriented while watching the monitor although the ROV DP could alleviate this problem. A fourth problem is the lack of a reliable navigation/tracking system (The above mentioned systems have yet to be tested in an actual ship's tanks).

Using ROVs is a very high tech approach requiring a great deal of operator training. It is also more expensive than alternative approaches. Not all tanks could be ballasted, further limiting the applicability of this approach.

6.9 Divers

Divers are routinely used for inspections of offshore platforms where the water clarity permits such inspections. Divers can perform visual, magnetic particle and ultrasonic inspections underwater. Underwater equipment for both magnetic particle and ultrasonic inspection is readily available. Divers could perform similar inspections inside a ballasted tank if the turbidity of the water is low enough.

The ideal diver is one who is trained in visual inspection of ships structure and is certified to conduct magnetic particle and ultrasonic inspections. Such divers are rare, indeed. To compensate, the diver can be given a video camera and ultrasonic test transducers attached by umbilicals to the deck. On deck, certified inspectors can view and interpret the inspection results and pass instructions back to the diver. The need to pass instructions to the diver greatly complicates the process. It is difficult to instruct the diver where to look next when only the video camera view is available on deck. There is no substitute for diver training in NDT techniques. Diver training in structural inspection is likewise necessary if divers are to be used effectively.

For safety reasons, two divers should always be in the tank during an inspection. The time a diver can remain in the water is limited, restricting the amount of inspection that can be done without relief divers. Though not recommended, a two diver team sometimes works with one diver in the water and one diver on deck resting and standing by in case of an emergency. The two divers reverse roles periodically allowing for a full day of inspection.

On large ships, with deep tanks, the depth of dives required may prevent more than one 30 minute dive per day. Decompression chambers should be nearby if such dives are performed. However, this problem could be eliminated by only partially ballasting the tank while inspecting the lower structure and filling the tank for inspection of the upper structure.

The safety limitations and equipment requirements for diving make this a costly means of inspection. Highly trained divers command premium prices. Only those tanks that can be cleaned sufficiently and then ballasted can be inspected. The cost of ballasting tanks is a significant part of the cost of this method. Ballasting costs are on a par with the rafting method of inspection discussed in 6.4.

6.10 Robotics

The Battelle Pacific Northwest Laboratory in Richland, Washington has developed waste tank inspection equipment for the Department of Energy Waste Remediation Programs that may be of potential use to Coast Guard tanker inspections. Long-reach, teleoperated manipulators have been developed that can both survey the internals of waste tanks and then excavate and retrieve wastes. The manipulators have a reach capability of up to 75 feet, with payloads up to 45 pounds. The manipulators can be inserted through a 14 inch diameter opening and can carry a high resolution video camera. Laser range finders can be used to map the operating envelope of the manipulator when used with a collision avoidance system.

Control systems have been developed that allow the end of the manipulator to be "flown" around the tank. This motion is simpler and more productive than controlling each joint of the manipulator individually. An entire system described above could run anywhere from several hundred thousand to well over a million dollars depending on specific requirements.

One such system is called the three dimensional snake. It could be deployed down a butterworth opening and "flown" to any location within 15 or 20 feet of the butterworth end. Full pitch and yaw freedom exist at each joint, allowing complete freedom in vertical and horizontal positioning of the end.

Figure 26, provided by Battelle Pacific Northwest Laboratories, is a conceptual drawing of a counter-weighted telescoping arm. This system has a much higher payload but limited multi-directional maneuverability.

A chain link arm is another possible configuration. As the arm is extended it travels down the arm guide out the opening at the bottom, where it is deflected out horizontally by a declination

guide. The arm can then be retracted in and out to different lengths, and tilted up or down.

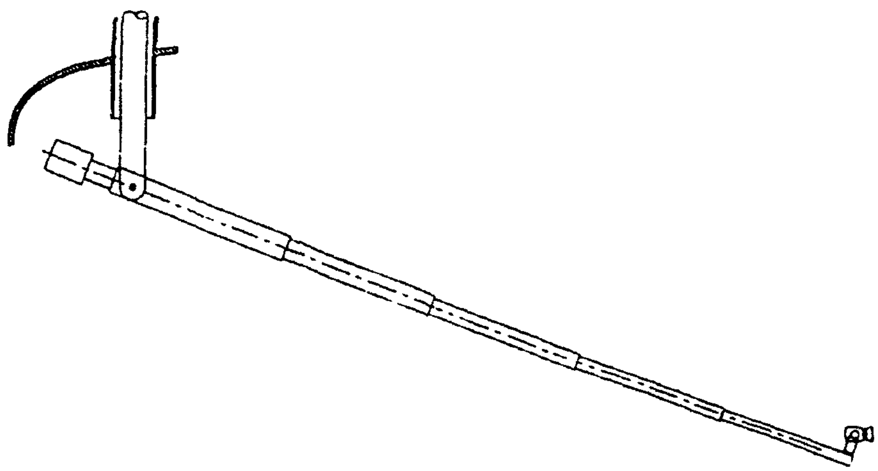


Figure 26 Possible Robotic Arm Configuration

These systems have as their major advantage keeping the inspector free from the hazards of tank entry. There are several problems that need to be looked at. The first is the cost. These systems can become very complex depending on specific requirements for vessel inspections and the more complex the more expensive. A second consideration is the size and bulkiness of the system. Due to the size and lack of lighting inside a tank the manipulator may have to be moved to different openings to fully cover one tank space. Moving the manipulators would require the use of a crane. A third consideration is the excessive amount of time involved with all this moving. Robotics is therefore not considered a practical method for routine ship inspections because of the time required to set up any known robotic system and to move it from tank opening to tank opening. There are systems that work but none that are practical to cover the large size of a tanker nor is it likely that a practical system can be developed. A tanker with say 21 tanks would need at least 21 and probably as many as 40 to 50 robotic systems built in to automate inspections. This could be done, but is cost prohibitive.

6.11 Access Summary

Table 10 summarizes the access enhancements discussed in this section. Many good access methods are available which require no further development work. However, all are expensive and time consuming to setup. The greatest access improvement would be for the Coast Guard to require new ship designs which permit access using the structure of the ship for platforms, ladders, and hand holds. Guidelines at least should be developed for use by designers which show structural features which enhance access with minimal cost impact.

Table 10 Access Enhancement Methods

Method	Application	Advantages	Disadvantages
Portable Ladders	Provide access to upper areas of tanks within ladder capability.	Easy to place in tank and setup. Simple, proven technique.	Difficult to maneuver within the tank. Weight makes it hard for one person to handle. Dangerous to climb high, unguarded ladder.
Fixed Staging	Provide access to all areas of the tank.	Provides work platform for repairs as well as inspection. Readily available.	Costly to stage many tanks. Labor intensive to setup.
Rafting	Provide access to upper areas of tank bulkheads. Limited overhead access.	Provides good access to bulkheads at various levels. Can be used in moderate seas.	Can't access overhead structure. Danger of getting trapped in tank.
Suspended Work Platforms	Provide access to upper areas of tanks.	Portable, easy assembly, air powered. Can be performed at sea, in port or at anchor.	Costly. Difficult to attach rigging to overhead.
Articulated Bucket	Access to upper areas of tanks.	Once in place provides quick movement within limits of arms reach.	Need crane to set in place and relocate.
Magnetic Crawler	Ultrasonic testing of inaccessible areas.	Portable, easy to use. Access to where a person can't go.	Crawler may lose contact on heavily rusted surface. Accuracy diminished on poor surfaces.
Remotely Operated Vehicles	Remote underwater inspection of tanks.	Inspector free from hazards of tank entry. Access to all areas of flooded tank.	Time consuming. Costly. Difficult to navigate. Umbilicals can tangle in frames.
Divers	Underwater inspection of tank structure.	Access to all parts of ballasted tank. Visual, magnetic particle or ultrasonic inspection can be conducted.	Requires highly trained divers. Inspection time limited. Ballasting tanks is expensive.
Robotics	Provide unmanned access to upper structure.	Inspector free of hazards of tank entry. Can perform a variety of NDT tasks and carry video camera.	Very expensive. Crane required for positioning. Cleaning surfaces for NDT is difficult.

References

1. ASNT Standard For Qualification and Certification of Non-destructive Testing Personnel. ASNI/ASNT CP-189-1991, ASNT 1989.

2. Betz, Carl, Principles of Magnetic Particle Testing. Magnaflux Corp., 1988.

3. Bracket, R.L., W.J. Nordell, and R.D. Rail, Underwater Inspection of Waterfront Facilities: Inspection Requirements Analysis and Nondestructive Testing Technique Accessment. March 1992.

4. Cushing, John M. Jr., Weld Surface Microstructure As An Indicator of Fatigue Life For Marine Structures. June 1992.

5. Dover, W.D. and P.A. Frieze, Underwater NDE Centre Joint Industry Project on Inspection Reliability-Probability of Sizing, DOC NDE/87/111. November 1987.

6. Eastman Kodak Co., Radiography in Modern Industry. 1980.

7. Holtzman, Robert S. Lt., USCG. Advancements In Tankership Internal Inspection Techniques.

8. Komorowski, J.P., D.L. Simpson, and R.W. Gould, "Enhanced Visual Technique for Rapid Inspection of Aircraft Structures," Materials Evaluation, December 1991.

9. Marine Structural Integrity Programs (MSIP), SSC-365, 1992.

10. Materials Evaluation Magazine. Special Issues on various NDE techniques: Radiography - April 1991, Liquid Penetrant Testing - July 1987, Acoustic Emission Testing - February 1988, Underwater NDT Issue - April 1983/Vol. 41/No. 5, ASNT Spring Conference - March 1991.

11. McMaster, Robert C., Non-destructive Testing Handbook. ASNT 1959.

12. Reighard, M.K., T.W. Van Oordt, and N.L. Wood, "Rapid Ultrasonic Scanning of Aircraft Structure," Materials Evaluation, December 1991.

13. Spanner, Jack C., Acoustic Emission: Techniques and Applications. Intex Publishing Corp., 1974.

14. Underwater Inspection of Steel Offshore Installations: Implementation of A New Approach, UEG, June 1989.

15. Implementing Recommended Practice No. SNT-TC-1A, 1988 Edition.

16. NDE Handbook: Non-destructive Examination Methods for Condition Monitoring, Edited by Knud G. Boving, Butterworths, 1989.

17. Lorenz, Peter G., "The Science of Remote Visual Inspection (RVI): Technology, Applications, Equipment," Olympus Corporation, 1990.

Sources Contacted for this Report

ABS Americas
263 North Belt East
Houston, TX 77060 USA
(713) 873-0700

Aerospace Industries Association of America
1250 I Street, N.W.
Washington, D.C. 20005
Phone (202) 371-8400
Fax (202) 371-8470

American Institute of Steel Construction
1 E. Wacker Drive, Suite 3100
Chicago, IL 60601-2001
Phone (312) 670-2400
Fax (312) 670-5403

American Iron and Steel Institute
1133 15th Street, N.W.
Washington, D.C. 20005
Phone (202) 452-7100/7265
Fax (202) 463-6573

American Railroad Bridge and Building Association
18154 Harwood Avenue
Homewood, IL 60430
(312) 799-4650

Allan Carter
Amida Industries, Inc.
590 Huey Road
Rock Hill, SC 29730
1 (800) 433-3026

Dave Sucharski
ARCO
Long Beach, CA
(310) 590-4527

Association of American Railroads Research and Testing Department
50 F Street, N.W.
Washington, D.C. 20001
(202) 639-2250

Association for Bridge Construction & Design
501 County Office Building
Forbes Ave and Ross Street
Pittsburgh, PA 15219
Phone (412) 355-5877
Fax (412) 355-5888

Association of Iron & Steel Engineers
3 Gateway Center, Suite 2350
Pittsburgh, PA 15222
Phone (412) 281-6323
Fax (412) 281-4657

Battelle
Pacific Northwest Laboratories
Battelle Blvd.
P.O. Box 999
Richland, WA 98352
(509) 375-2159

Eric W. Gifford, Robotics Service Engr.
Benthos, Inc.
49 Edgerton Drive
North Falmouth, MA 02556-2826
(508) 563-1000 / 1 (800) 446-1222

Grahm Levy
Bright Star Industries
Hanover Industrial Estates
380 Stewart Road
Wilkes-Barre, PA 18706
1(800) 631-3814

George Sherman
Butterworth Tanker Cleaning Systems, Inc.
(713) 821-7300

Case Western Reserve University
Edison Sensor Technology Center
Bingham Building
10900 Euclid Ave
Cleveland, OH 44106
(216) 368-2935

John Kimble
Chevron Shipping Co.
555 Market St.
San Francisco, CA 94105
(415) 894-0146

Colorado State University
Engineering Research Center
Foothills Campus
Fort Collins, CO 80523
(303) 491-8657

Joe Bango, President
Connecticut Analytical Corporation
70 Raton Drive
Milford, CT 06460
(203) 876-2720

Dave Orlosky
Cramer & Lindell Engineers, Inc.
P.O. Box 600
277 West Main Street
Niantic, CT 06359-0600
(203) 739-3767

Rodney Moore
Deep Ocean Engineering
1431 Doolittle Drive
San Leandro, CA 94577
(510) 562-9300

Karen Huber
DORCY International, Inc.
3985 Groves Road
Columbus, OH 43232
(614) 861-5830

Elecromatic Equipment Co., Inc.
600 Oakland Avenue
Cedarhurst, NY 11516
(516) 295-4300

Electro-Optical Products Division
7635 Plantation Road
Roanoke, VA 24019
Attn.: Night Vision Marketing
(703) 563-0371

Dave Wood
Eveready Battery Company, Inc.
St. Louis, MO 63164
1(800) 526-4727

Jim Balman
Fulton Industries
135 Easst Linfoot Street
Wauseon, OH 43567
1(800) 537-5012

Melanie L. Goddard
Koehler Manufacturing Co.
123 Felton Street
Marlborough, MA 01752
(508)485-1000

Johns Hopkins University
Center for Non-Destructive Evaluation
102 Maryland Hall
34th and North Charles Street
Baltimore, MD 21218
(301) 338-6115

Laser Technology, Inc.
1055 West Germantown Pike
Norristown, PA 19403
Phone (215) 631-5043
Fax (215) 631-0934

Lehigh University
Center for Advanced Technology for
Large Structural Systems (ATLSS)
Fritz Engineering Lab #13, Room 602
Bethlehem, PA 18015
(215) 758-3535

Amy
Mag Instrument, Inc.
1635 South Sacramento Avenue
Ontario, CA 91761-7769
(714)947-1006

Thomas Joseph
Magnum Products, Inc.
433 Industrial Park Drive
Berlin, WI 54923
1(800) 926-9768

Derek Withers
Marine Inspection Products
Town Mills
Mill Road Industrial Estate
Radstock, Bath BA35TX
011 44 0761 432305

Martin F. Bowen
Marquest Group
Telepresence Division
8 Otis Park Drive
Bourne, MA 02532
(508) 759-1311

Nancy Wood/Joseph Flattery
McDonnell Aircraft Company
Dept. 080, MC 0011300
P.O. Box 516
St. Louis, Missouri 63166

Gail Giberti
Monroe Infrared Technology
P.O. Box 1058
Kennebunk, ME 04043
1 (800) 370-0163

David Kailer
NDT International, Inc.
711 Creek Road
West Chester, PA 19382
(215) 793-1700

National Association of Corrosion
Engineers
P.O. Box 218340
Houston, TX 77218
Phone (713) 492-0535
Fax (713) 492-8254

National Association of Marine
Surveyors
305 Springhouse Lane
Moorestown, N.J. 08057
(609) 722-5515

New Mexico State University
Center for Transportation Research
College of Engineering, Box 3CE
Las Cruces, N.M. 88003-0083
(505) 646-3135

New Mexico State University
Center for Electronic Vision and
Robotics
Department of Electrical & Computer
Engineering
Las Cruces, N.M. 88003
(505) 646-3301

New York Institute of Technology
Science and Technology Research Center
8000 North Ocean Drive
Dania, FL 33004
(305) 923-0551

JP Maldonado
Night Vision Enhancement Co., Inc.
P.O.Box 266
Emmaus, PA 18049
(215) 391-9101

Penn State University
Nondestructive Testing & Evaluation Programs
159 Materials Research Laboratory
University Park, PA 16802
(814) 863-2843

James Mitchel
Physical Acoustics Corporation
P.O. Box 3135
Princeton, NJ 08543-3135
(609) 844-0800

Purdue University
Applied Ultrasonics and Electromagnetic Signal Processing Laboratory
School of Electrical Engineering
West Lafayette, IN 47907
(317) 494-3563

Rochester Institute of Technology
Center for Imaging Science
One Lomb Memorial Drive
Rochester, N.Y. 14623
(716) 475-5170

Scaffold Industry Association
14039 Sherman Way
Van Nuys, CA 91405-2599
Phone (818) 782-2012
Fax (818) 786-3027

Scaffolding, Shoring & Forming Institute
c/o John H. Addington
Thomas Associates, Inc.
1230 Keith Building
Cleveland, OH 44115
Phone (216) 241-7333
Fax (216) 241-0105

Society for the Advancement of Material & Process Engineering
P.O. Box 2459
Covina, CA 91722
Phone (818) 331-0616
Fax (818) 332-8929

William McDermott, Jr.
Spider Staging Corporation
254 Revere Street
Canton, MA 02021-2921
(617) 828-8343

Gerald Beil
Stageaway Vessel Services
5300 N. Channel Avenue
Portland, OR 97217
(503) 286-2464

Steel Deck Institute
P.O. Box 9506
Canton, OH 44711
Phone (216) 493-7886
Fax (216) 493-7886

Steel Structures Painting Council
4400 5th Avenue
Pittsburgh, PA 15213-2683
Phone (412) 268-3327
Fax (412) 268-7048

Steel Tank Institute
570 Oakwood Road
Lake Zurich, IL 60047
Phone (708) 438-8265
Fax (708) 438-8766

James F. Blom
StereoGraphics Corporation
2171 East Francisco Blvd
San Rafael, CA 94901
Phone (415) 459-4500
Fax (415) 459-3020

Jim Browne
Stewart R. Browne Mfg. Co., Inc.
Dept 87
1165 Hightower Trail
Atlanta, GA 30356
(404) 993-9600

Streamlight
1030 West Germantown Pike
Norristown, PA 19403
(215) 631-0600

Peter Simpson
Subspec Oceanics LTD
Kirkton Avenue
Pitmedden Road Industrial Estate Dyce
Aberdeen
(0224) 771888

Texas A&M University
Mechanical Engineering Department
College Station, TX 77842
(409) 845-2944

Texas A&M University
Materials and Structures Laboratory
College Station, TX 77843
(409) 845-7512

Texas A&M University
Texas Transportation Institute,
Structural Systems Division
Research Center
College Station, TX 77843
(409) 845-4495

Michael Starks
3-D TV Corporation
P.O. Box Q
San Rafael, CA 94913
Phone (415) 479-3516
Fax (415) 479-3316

Cue Willis
Unitron
170 Wilbur Place
P.O.Box 469
Bohemia, NY 11716
(516) 589-6666

University of New Hampshire
Engineering Design & Analysis Lab
Kingsbury Hall 101
Durham, N.H. 03824
(Underwater Robotics)
(603) 862-1356

University of New Hampshire
Marine Systems Engineering Laboratory
Science and Engineering Building
Durham, N.H. 03824
(Underwater Robotics)
(603) 862-4600

University of Wisconsin - Milwaukee
Structural Testing Laboratory
Department of Civil Engineering
P.O. Box 784
Milwaukee, WI 53201
(414) 229-5201

Bruce Pellegrino
Visual Inspection Technologies, Inc.
27-2 Ironia Road
Flanders, NJ 07836-9124
(201) 927-0033

Andrew Owen
Inframetrics, Inc.
16 Esquire Road
No. Billerica, MA 01862-2598
(508) 670-5555

APPENDIX A Interview with MIO New York Marine Inspectors - Innovative Inspection Techniques

5/21/92 Marine Inspection Office, New York NY

Two senior civilian (retired USCG) inspectors were interviewed, with occasional input from several other inspectors.

- CG structural inspections are limited to evaluating the seaworthiness of vessels and, for tank vessels, their ability to prevent spills of oil at sea. During a structural inspection, every space is inspected, but the level of effort varies from space to space.

- Whenever possible, structural inspections are conducted with the vessel in drydock, so that external and internal structural inspections can be combined. Tanks are generally gas-free and certified for hot work, making access much easier. Many of these inspections are conducted overseas.

- CG inspectors are limited to equipment which they can carry with them. The CG does not own, nor do inspectors carry any portable staging, high-resolution optical or video equipment, rafts, or non-destructive testing equipment. Any equipment or services used to enhance inspector access (staging, cherry-pickers, ballasting and rafting, etc, must be provided by the vessel, or by the shipyard or private contractors at the expense of the vessel owners. This also applies to detailed inspection equipment (ultrasonic thickness gaging, infrared thermography, dye penetrant, etc.)

  The primary work of the CG inspectors is visual scanning of structure, often from a distance. Inspectors cannot use staging, rafting, high-power lighting, sophisticated telescopic or video equipment, or any other physical or visual access enhancement techniques for overall screening purposes; such techniques can only be called for if preliminary screening indicates a specific localized problem which requires more detailed inspection. Inspectors are not allowed to call for any detailed inspection equipment (thickness gaging, etc) unless the initial screening and a subsequent close-up visual inspection indicates a specific need for NDT techniques.

- CG inspectors are no longer allowed to climb the sideshells of VLCC's or ULCC's.

- The inspectors interviewed considered a rafting survey, in which a tank is filled with seawater progressively while a rafting inspection crew inspects the internal structure, to be an effective means of scanning for problems. However, since rafting involves an expense to the vessel owners, the Coast Guard cannot use rafting as a scanning technique. The inspectors considered rafting in a moored vessel to be a dangerous practice, and only knew of a few instances of CG inspectors rafting in a vessel while underway, a practice they considered to be even more dangerous.

- The inspectors divided the major structural problems into three major categories:

  External Damage. This occurs as a result of collisions or other contact between vessels and fixed structures, and as a result of wave damage. The damage is generally to the sideshell and the sideshell longitudinal framing, with the exception of grounding damage, which is usually to the bottom and bottom internal framing. The most effective means of scanning for external damage is to sight the sideshell plating from the outside for irregularities, dishing, and dents. If a vessel is afloat and deeply loaded this technique might not be suitable. Sighting the sideshell longitudinals from the inside, checking for irregularities or lack of parallelism, is somewhat less effective, but sometimes necessary. If these scanning techniques indicate irregularities, detailed close-up inspections, at the expense of the vessel owner, are justified.

  Longitudinal Stress Damage. This occurs as a result of longitudinal flexing in a seaway or as a result of improper load distribution. The most likely place for damage to occur is in the longitudinal framing members of the bottom and deck, and at intersections of those members with transverse structural members. Such damage usually involves major structural cracking or weld failures, which will be found by an inspector walking the tank bottom. Problems of this type which are found in the bottom often involve related problems in the deck structure, and various methods of gaining access to the underdeck area may be justified.

  Corrosion Damage. This generally occurs near the ballast water level inside or near the load or ballast water lines outside the vessel. If scanning techniques indicate potential problems, detailed inspections including ultrasonic thickness gaging may be ordered, at the expense of the vessel owner.

- One of the inspectors here has had some experience with infrared thermography. He thinks that this technique has promise for non-contact inspections of welds. However, it requires close proximity and is too slow to be used as a scanning technique. If one was close enough to the structure to use this, one would be close enough to see any serious cracking or failed welds. The principal use of infrared thermography is to inspect the soundness of repair welds, and it appears to be an improvement, in terms of efficiency, over X-ray, dye-penetrant, and other tests for this use.

APPENDIX B Interview with MSO New Orleans Marine Inspectors - Innovative Inspection Techniques

LCDR Eric Nicolaus (Asst. CID)
LCDR Dick Kulak
LT Linda Fagan
LT Mark Hamilton

- The inspectors explained CG policy concerning inspection equipment other than that carried by the inspectors. Any equipment needed to improve access (staging, rafting, high powered lighting, climbing equipment, cranes, etc) is provided at the vessel owner's expense and only if the inspector has a specific reason, meaning hard evidence of a problem that requires access. Detailed inspection equipment like audiogaging equipment is also a vessel expense and is only ordered if the screening stage of the inspection reveals evidence of a problem that requires more detailed inspection. It is not uncommon for a vessel captain or owner to protest to the OCMI an inspector's request for equipment to provide better access and for the inspector's request to be overruled by the OCMI.

- Some inspectors have used high-powered lighting (sodium-vapor lights are one example, although the warm-up time is inconvenient) to enhance visibility in the screening stages of inspections of large spaces. They found these lights to be very valuable, especially in combination with binoculars. Most felt that the best improvements in screening techniques would come from use of high-intensity lighting in combination with magnification.

- Inspectors would like to try night-vision equipment; magnification would be required for this equipment to be of use.

- The number of regulations which apply to various types of vessels, and the frequency with which those regulations are changed, has required younger inspectors in training to concentrate on the regulations rather than on a detailed knowledge and understanding of ship structure.

- The CG does not set absolute requirements for periodic inspection of specific spaces. Not all spaces on a large vessel can be given a detailed inspection every time. While attempts are made to rotate the detailed effort from one inspection to another, certain spaces in some vessels, especially vessels that change inspection ports, may slip through the cracks. The inspectors felt that a system which details which spaces were inspected in each inspection might be better. There are precedents for this: the classification societies operate this way, and cargo tanks on TAPS vessels are required to be staged for CG inspections because of the large number of structural failures in vessels on the Alaska route.

- Better access to vessel and class inspection and structural repair history would benefit inspectors by allowing them to concentrate their effort in those areas in which problems are likely to occur.

APPENDIX C Interview with MSO Portland Marine Inspectors - Innovative Inspection Techniques

The Portland Marine Safety Office inspects a number of large vessels, a significant proportion of which are tankships. A large part of their work is done in the shipyards in the Portland area. Virtually all inspections of deep-draft vessels by inspectors from this office are conducted with the vessels in drydock at shipyards in the Portland area. Most inspections are done by a single inspector.

- For ships which are subject to the Critical Areas Inspection Program (CAIP) (detailed in COMDTPUB P16700.4), extensive and expensive access techniques are commonly employed for the screening stages of cargo space inspections. These include rafting of tanks and extensive staging of tanks. All of the Trans-Alaska Pipeline Service (TAPS) vessels and a number of other vessels with individual or class histories of major structural failures are subject to the CAIP program. It takes 5 days for a good crew of experienced inspectors to inspect a TAPS vessel. A normal non-CAIP inspection takes one inspector three or four days. Present manning levels and workloads would not permit inspections like those in the CAIP program for every vessel.

- The cost to erect and remove staging is approximately $5000 per tower, and 20 towers might be required to completely stage one large cargo tank. For vessels not subject to the CAIP, staging and other enhanced access techniques are only justifiable when the initial screening stages of an inspection reveal suspected structural problems.

- Inspectors from this office often conduct inspections concurrently with an independent surveying team working for the vessel owner. Such a team typically includes a steel surveyor, an NDT technician, and a recorder. Inspectors from the Portland office have typically enjoyed good relations with shipyard repair personnel, vessel crews and owners, independent surveyors, and with classification society surveyors.

- Inspectors would like to have a good, easily carried high-intensity flashlight. They have used the Oreck police lights, but these are too heavy to carry around continuously.

- Binoculars have been used by some inspectors to improve visual inspections, but they are difficult to carry. In addition, powerful lights are necessary to cast sufficient light on distant areas for viewing with binoculars (the optics of small, lightweight binoculars cut light levels somewhat). Such lights are too cumbersome, especially when carried along with binoculars. It is difficult for one person to use a flashlight and binoculars together to light up and inspect a particular location.

- Inspectors have used non-carryable high intensity lighting (theatre lights, etc.). Spotlight-type lighting was found to be useful, but it requires an operator, there is rigging time and expense involved, it is not intrinsically safe, and, as an owner-expense item, it can by

present policy only be justified to conduct a detailed inspection of a suspected problem uncovered during a screening inspection.

- Floodlights (sodium-vapor, mercury-vapor, etc.) have been tried, but they blind the inspectors.

- There is some duplication of effort between the CG, independent surveyors hired by the vessel owner, and classification-society (CS) surveyors. Portland inspectors accompany independent or CS surveyors whenever possible, especially when staging or other enhanced access equipment has been made available. The OCMI in Portland can accept and has accepted CS or independent surveys done with CG oversight as part or all of the CG structural inspection. The CG, however, is required to do a "close-up visual inspection" in every space during every inspection. CS surveyors generally inspect tanks on a rotating basis, not seeing each tank at each survey, and often their level of thoroughness does not approach the CG's idea of a close-up visual inspection.

  The inspectors and the OCMI felt that more coordination between the Coast Guard and the ABS and independent surveyors could potentially decrease the CG inspection workload without any compromise in the thoroughness of the inspections.

- The people in the Portland office felt that they received very good cooperation from vessel owners and shipyards in matters involving owner expenditures, particularly with regard to the use of staging. This cooperation often goes far beyond what is required of non-CAIP vessel owners by law or regulation. However, the owners don't have to provide this level of assistance. Large shipping companies with bases in the local area are much more likely to be cooperative than small independents. In Portland, those large companies account for a large proportion of the vessels inspected. Regulations requiring that vessel owners provide CAIP-level access to CG inspectors would insure that all vessels received uniformly thorough inspections, however, the inspection workload would increase, since CAIP inspections take longer.

- Improvements in vessel construction to make vessels more "inspector-friendly" would help greatly. Better and more ladders, some method of improved access to the deckhead and stringer platforms would be helpful. However, inspectors cautioned that some suggested improvements, such as making some sideshell longitudinals wider to function as walkways, might result in stress concentrations which would cause structural failures.

- A company named NETS has employed a video system for tank inspections. The system consists of a pole which fits down a tank cleaning opening, with a video camera with 10X magnification and a directional lighting system which travels up and down on the pole and can pan vertically, horizontally, and can zoom. The display is located above deck and is monitored by a naval architect. BP contracts with NETS to assist during their tanker surveys. The system has no articulating capability - the camera remains

directly below the deck opening from which it is inserted. No personnel are required in the tank.

The Portland inspectors have seen this system in use during an independent survey (of a British Petroleum tanker). It was seen to be useful for inspections of the deckhead area which is hard to reach by any other means, but because it was limited to the area around the deck opening through which it was inserted, it was necessary to move it several times to cover one tank.

- CAIP records are kept on board the vessels. This makes past inspection history much more readily available to subsequent inspectors and surveyors than for other vessels. Inspectors feel that access to the details of past CG inspections (and also to ABS and independent surveys reports) would be helpful.

- Portland presently has no civilian inspectors, although one is being hired to help with increased fishing vessel inspection responsibilities due to the Commercial Fishing Industry Vessel Safety Act. In some offices, like New York, Inspectors in New Orleans (where there are no civilian inspectors) and in New York (where a significant proportion of the inspectors are civilians) felt strongly that civilian inspectors added an important aspect of continuity to an inspection office. CDR Curelli, the Chief of Inspection in Portland agreed that vessel owners found it easier to deal with civilian inspectors who had been at the same office for a long time, since they (the owners) knew what to expect in terms of policy. However, he also had found that small branch offices staffed by civilian inspectors tended to evolve policies that diverged from the standard, and that the rotation of CG inspectors prevented this and insured that inspection policies remained more uniform throughout the country.

- The OCMI, Capt. Townsley, felt that information from all records of an inspection, including worklists, 835 forms, and inspector diaries should be retained in electronic form as a permanent part of the vessel's inspection history. This would allow trends in vessel maintenance and structural problems to be tracked not only for a particular vessel, but also by owner, location, and other factors.

  Field inspectors in all locations have complained that the coding required for entry of information into MSIS represents a significant time expenditure, with little apparent return. The purpose of that coding is to facilitate statistical analysis of inspection data. The entry of more information in a format suitable for trend tracking or other analysis would involve more of this type of coding, and unless the system were improved considerably, would result in more paperwork for inspectors. Inspectors themselves would prefer direct access to the text of diaries, worklists, and 835's from previous inspections. Since these are already kept in electronic form in many offices, this type of access would not require any extra work on the part of the inspectors.

- CID CDR Curelli noted that the requirements placed upon inspectors for experience and knowledge of regulations are presently burdensome and are increasing.

- Recent requirements for inspection of Ready Reserve Fleet vessels have increased the inspection workload.

APPENDIX D Interview with MSO Honolulu Marine Inspectors - Innovative Inspection Techniques

- A large number of inspectors warned strongly against concentrating on high-tech, expensive equipment rather than on the training and support of inspectors. They feel that streamlining their administrative duties to provide more time for actual inspections would be the most effective way of increasing inspection coverage.

- Inspectors felt that their level of experience is the single most important factor in the effectiveness of inspections.

- Inspectors feel that physical mobility and access are very important due to the complex structure inside tanks. In particular, techniques such as photography and video scanning, which present a 2D picture of a 3D structure, are limited by in usefulness by obstructing structure and shadows.

- The level of expense which vessel owners should be required to incur to provide enhanced access to inspectors should be related to the vessel's past history of structural problems and of cooperation with inspectors. It is not reasonable to expect vessels with no history of problems to provide expensive access enhancement such as staging or rafting to CG inspectors.

- Records of the history and location of problems should be kept for all vessels, not just those subject to CAIP. This information would be beneficial to inspectors conducting subsequent inspections.